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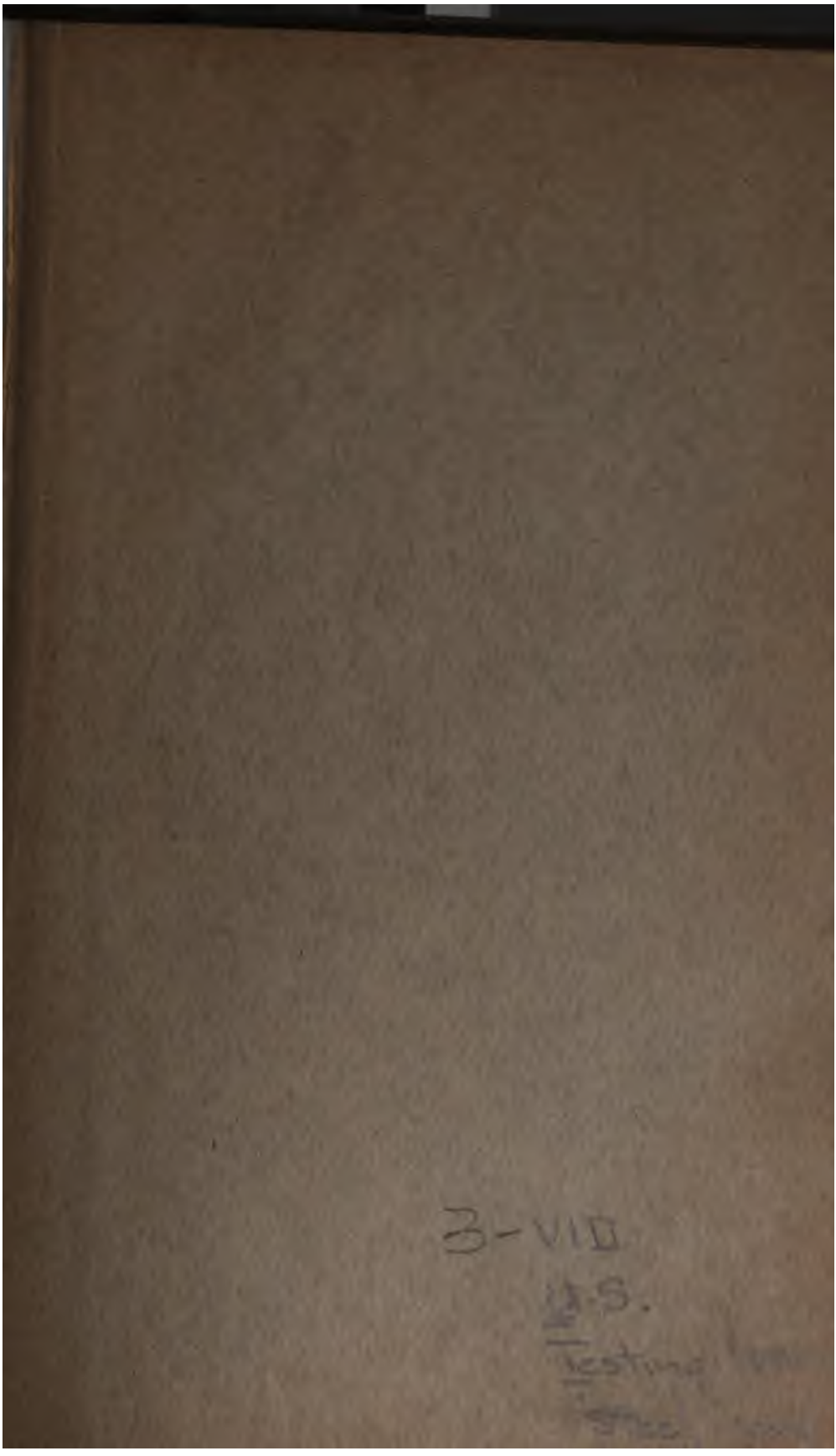
B-VIII
U.S.

REPORT

ON THE

PRELIMINARY INVESTIGATION OF THE PROPERTIES

OF THE

COPPER-TIN ALLOYS,

MADE UNDER THE DIRECTION OF THE

COMMITTEE ON METALLIC ALLOYS,

UNITED STATES BOARD TO TEST IRON, STEEL, AND OTHER METALS,

ROBERT H. THURSTON, CHAIRMAN,

AT THE

MECHANICAL LABORATORY OF THE STEVENS INSTITUTE OF TECHNOLOGY.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1879.

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EDITOR'S PREFACE.

The investigation of the properties of alloys of copper and tin here reported upon, was entered upon under a resolution of the United States Board to Tes t Iron, Steel, and other Metals, passed April 17, 1875, directing a determination of "the mechanical properties and of the physical and chemical relations of alloys of copper, tin, and zinc," and under the arrangement of committees approved by the board, April 23, 1877, which assigned to the committee on alloys the duty of "assuming charge of a series of experiments on the characteristics of alloys and an investigation of the laws of combination."

This research was conducted in the Mechanical Laboratory of the Department of Engineering of the Stevens Institute of Technology under the authorization of the Trustees, who, although without power to assume responsibility involving pecuniary risk, cordially gave the work their countenance, and permitted the use of every facility which the Institute afforded in the prosecution of the work, and, as have the President and members of the Faculty, aided most effectively wherever opportunity offered.

This preliminary study of a wide and important field will, it is hoped, prove to have been so satisfactorily done that a repetition of the work may never be required, and that, in the future, research may be thus profitably confined to matters of detail in those parts of this field which are here shown to be of most promise and where investigation may be most certain to yield liberal returns.

The principal assistant and observer in this extended and extremely laborious work has been Mr. William Kent, without whose intelligent assistance we should have often found it necessary to suspend work temporarily, and should have been compelled to take a very much longer time for its completion. I cannot speak too highly of his conscientious and skillful work, not only at the testing-machines, but in working up results. He is to be credited also with many valuable suggestions and with some of the very ingenious devices which have greatly abridged the work. The committee are also indebted for similar assistance to Mr. J. E. Denton, assistant in charge of the Mechanical Laboratory, to Mr. Theo. F. Koezly, and to Mr. and Mrs. F. T. Thurston. The latter were invaluable coadjutors in the preparation of the report, and especially of its illustrations. The conscientious accuracy of their work is best indicated by reference to the plates which accompany this report. Mr. F. T. Thurston is especially entitled to credit for essential assistance rendered in editing this report, every page of which has passed under his revision.

With their skillful aid, the endeavor has been made to carry out the plan of the committee faithfully and with all possible thoroughness and accuracy.

The intention of the committee was, not to determine the character of chemically pure metals, melted, cast and cooled with special precaution, but to ascertain the practical value of commercial metals, as found in the markets of the United States, melted in the way that such alloys are prepared in every foundery for business purposes, and cast and otherwise treated in every respect as the brass-founder usually handles his work. The endeavor has been to determine what is the practical value, to the brass-founder and to the constructor, of commercial materials treated in the ordinary manner and without any special precaution or any peculiar treatment.

The investigation of the effect of various kinds of fluxes and methods of fluxing and of special methods of treatment of the alloys after casting, is reserved for a future research.

The result of this investigation has been the approximate determination of the mechanical properties of all alloys of copper and tin.

The set of diagrams representing the method of variation of each of these properties with variation of composition, will exhibit this result most satisfactorily.

Those diagrams form a very concise compendium of the whole work. Other diagrams are given, of which the curves exhibit the behavior of every test-piece from the instant of application of the initial load to the end of the test. The *fac similes* of the Autographic Strain Diagrams obtained automatically by the use of the Autographic Recording Testing-Machine, designed by the writer, also exhibit the characteristics of each alloy as described by itself, and give the strength, resilience, modulus of elasticity, and homogeneousness of every portion of every bar of metal made.

In the text of the report will be found a statement of the more important facts determined, and the tables appended contain all the results of observation. The whole forms a collection of facts that will probably repay a vastly more complete analysis and more careful study than it has been possible to give them.

Little more has been done than to determine facts; their comparison and the determination of laws and of corollaries is a still greater task, and months might be profitably spent in the work.

Very respectfully,

R. H. THURSTON,
Chairman of Committee,
Editor of Report.

MECHANICAL LABORATORY,
DEPARTMENT OF ENGINEERING,
STEVENS INSTITUTE OF TECHNOLOGY,
February 25, 1879.

To the United States Board appointed to test Iron, Steel, and other Metals:

GENTLEMEN: The undersigned, a Committee appointed by you with instructions "to assume charge of a series of investigations of the characteristics of alloys," present herewith a report upon the Copper-Tin Alloys.

This research has been made under the direction of this Committee and under the direct supervision of its chairman. The Committee will, immediately upon its completion, present a similar report upon the Copper-Zinc alloys, and a report upon the Triple Alloys of Copper, Tin, and Zinc will follow. The work has been done in the same way and under the same direct supervision as that on the copper-tin alloys.

The Committee take great pleasure in presenting these reports to the Board. They represent the results of the first complete and systematic researches ever made upon these most important of all the alloys of useful metals. This work has been carefully planned, and the plans formed have been completely carried out. The result has been the complete exploration of a broad and most important field of which almost nothing was previously known. Ordnance-bronze, bell-metal, and speculum-metal, a few grades of brass and of the triple alloys, were the only alloys familiar to our founders and engineers.

The whole field has now been explored and the useful alloys are proven to occupy but a limited portion of its great extent, and it has been now shown that a comparatively narrow band extending from ordnance-bronze, on the one side of this triangular territory, to Muntz metal, on the other, contains all of the best of the generally useful alloys. This small portion of valuable territory having been pointed out and defined, its more minute study may be left for future investigators.

Your Committee desire to invite especial attention to, and to ask a careful study of, the strain-diagrams of the copper-tin and the copper-zinc alloys, and a still more careful examination of the graphical representation of the results of the research on the copper-tin-zinc alloys, as presenting most completely and satisfactorily the characteristics of all possible combinations of the metals used.

Very respectfully,

R. H. THURSTON,
L. A. BEARDSLEE,
DAVID SMITH,
Committee on Metallic Alloys.

A PRELIMINARY EXPERIMENTAL RESEARCH UPON THE MECHANICAL PROPERTIES OF SMALL CASTINGS OF THE ALLOYS OF COPPER AND TIN.

The part of this research which has been completed, and of which the results are given in the following pages, consists of an investigation of the strength, ductility, resilience, and other mechanical properties of the alloys of copper and tin, in the form of cast bars about 28 inches long and 1 inch square in section, prepared from the best commercial metals, simply ordinary precautions being taken to secure good castings. It was desired to learn, besides the properties of each particular alloy, the laws which connected these properties with the proportions of the component metals, and also whether alloys mixed in simple proportions of the chemical equivalents of the component metals possessed any advantages over other mixtures. It was reserved for a subsequent research to determine the effect of various methods of casting, of rapid or slow cooling, of casting under pressure, of using special fluxes, and of the effects of rolling and hammering.

Two series of these alloys were made, the first consisting of twenty-nine bars, of which twenty-three were mixtures of the metals in atomic proportions, four were mixtures made without regard to the atomic proportions, and the remaining two were a bar of copper and a bar of tin, each without admixture.

The second series comprised twenty bars, ranging from 97½ per cent. copper and 2½ per cent. tin to 97½ tin and 2½ copper, with a regular difference of composition between consecutive bars of 5 per cent. In addition to these alloys a few other bars of cast copper were made and one of cast tin.

After the bars were prepared they were tested first by transverse stress in the manner hereinafter described. The pieces remaining from the transverse tests were then turned into proper shape and tested by tensile stress. The ends of the tensile-test pieces were then tested by torsion. In general, each bar sufficed for one transverse, two tensile, and four torsional tests, and in some cases compression-test pieces were made, as described hereafter. The turnings made in shaping the tensile-test specimens were carefully saved for chemical analysis. Small pieces from each tensile specimen were saved for the determination of the specific gravity.

FIRST SERIES—COPPER AND TIN ALLOYS.

The metals used in preparing the first series of copper and tin alloys were procured from responsible dealers, and reported by them to be the purest commercial metals in market. The weighing was made with great care in the Physical Laboratory of the Stevens Institute of Technology, on a balance made by Messrs. Saxton and Bache for the United States Bureau of Weights and Measures. The metal weighed out for each bar was 4.5 kilogrammes (about 9.92 pounds), and the weighing was made in all cases to within one-tenth of a gramme, the balance being sensitive to a very much smaller weight. The error in weighing was less than $\frac{1}{20000}$ of the whole.

A similar balance was exhibited by the Bureau of Weights and Measures of the United States Treasury Department at the Paris Exposition of 1867, and is stated in Prof. F. A. P. Barnard's report to have

been sensitive to $\frac{1}{2000000}$ of the weight in each scale, and to have received the highest praise from eminent French authorities.*

The following table gives the composition of the alloys of the first series according to their atomic proportions and percentages of original mixture, and also according to chemical analysis made after the tests.

TABLE I.—ALLOYS OF COPPER AND TIN.—FIRST SERIES.

Composition by Original Mixture and Analysis.

Number.	Atomic proportion.		Percentage by original mixture.		Mean percentage by analysis.		Mean specific gravity.
	Cu.	Sn.	Cu.	Sn.	Cu.	Sn.	
1	1	0	100	0	.....	.....	8.947
2	96	1	98.1	1.9	97.89	1.90	8.564
3	48	1	96.27	3.73	96.06	3.76	8.649
4	24	1	92.80	7.20	92.11	7.80	8.694
5	.....	.....	90.00	10.00	90.27	9.58	8.669
6	12	1	86.57	13.43	87.15	12.73	8.681
7	.....	.....	80.00	20.00	80.95	18.84	8.710
8	6	1	76.32	23.68	76.64	23.24	8.565
9	.....	.....	70.00	30.00	69.84	29.89	8.932
10	4	1	68.25	31.75	68.58	31.26	8.938
11	.....	.....	65.00	35.00	65.34	34.47	8.947
12	3	1	61.71	38.29	62.31	37.35	8.970
13	12	5	56.32	43.68	56.70	43.17	8.682
14	2	1	51.80	48.20	51.62	48.09	8.560
15	12	7	47.95	52.05	47.61	52.14	8.442
16	3	2	44.63	55.37	44.52	55.28	8.312
17	4	3	41.74	58.26	42.38	57.30	8.302
18	6	5	39.20	60.80	38.37	61.32	8.192
19	1	1	34.95	65.05	34.22	65.80	8.013
20	3	4	28.72	71.28	25.85	73.80	7.948
21	3	5	24.38	75.62	23.35	76.29	7.835
22	1	2	21.18	78.82	20.25	79.63	7.770
23	1	3	15.19	84.81	15.08	84.62	7.657
24	1	4	11.84	88.16	11.49	88.47	7.552
25	1	5	9.70	90.30	8.57	91.39	7.487
26	1	12	4.29	95.71	3.72	96.31	7.360
27	1	48	1.11	98.89	0.74	99.02	7.305
28	1	96	0.557	99.443	0.32	99.46	7.299
29	0	1	0	100	.....	.....	7.293

Analyses of the ingot metal used in these alloys were made, with the following results:

	Ingot Lake Superior Copper.	Ingot Banca Tin.	Ingot Queensland Tin.
Metallic iron	0.013	0.035	0.035
Metallic zinc	none	none	none
Metallic silver	0.014	.....	.....
Metallic arsenic	none	none	trace
Metallic antimony	none	none	none
Metallic cobalt	.....	.....	none
Metallic bismuth	none	none	none
Metallic nickel	.....	.....	none
Metallic lead	trace	none	0.165
Metallic manganese	.....	.....	0.006
Metallic molybdenum	.....	none	none
Metallic tungsten	.....	.....	none
Metallic copper	99.420	none	none
Metallic tin	none	99.978	99.794
Suboxide of copper	0.537	.....	.....
Carbon	0.041	.....	.....
Matter insoluble in aqua regia	.....	trace	.....
	100.025	100.013	100.00

* United States Reports on Paris Exposition, Vol. III, p. 485.

All the bars were made in the brass foundry of the Mechanical Laboratory of the Stevens Institute of Technology, by an experienced brass founder, but considerable difficulty was met with in the cases of many of them in consequence of the variable and unusual proportions in mixtures adopted which necessitated different methods of treatment. Several bars had to be recast one or more times to secure even fairly good castings.

The crucibles used were made of a composition of plumbago and fire-clay. They were 6½ inches in height and 4¼ inches largest diameter, inside measurements. The furnace was an ordinary brass founder's furnace, furnished with a strong chimney draught. The fuel used was anthracite coal. In mixing, the copper was first melted and the tin added in the solid state, in small portions at a time, and the mixture thoroughly stirred with a dry wooden lath.

The first castings were made in dry sand molds, but so much trouble was given by irregular surfaces and blowholes that recourse was had to a cast-iron mold, which gave better results. When the metal was poured at too low a temperature into the cold mold it was sometimes slightly chilled, giving an irregular surface. This was remedied by heating the mold to a temperature somewhat below the melting point of the alloy, the highest temperature being given it in casting alloys containing the largest percentages of copper. In all cases the mold was placed in a vertical position while the metal was being poured and cooled. The following is a statement of the method of casting of each of the twenty-nine bars.

No. 1. All copper. Cast twice in dry sand mold. Bar broke in middle each time (probably by shrinkage). Cast in cold iron mold—surface uneven. Cast in hot iron mold—good.

No. 2. 97.89 copper, 1.90 tin. Cast in dry sand—good.

No. 3. 96.06 copper, 3.76 tin. Cast in cold iron mold—spongy appearance on surface. Recast in hot iron mold—surface somewhat streaked and irregular.

No. 4. 92.11 copper, 7.80 tin. In cold iron mold—surface bad. Recast in hot iron mold—good.

No. 5. 90.27 copper, 9.58 tin. In hot iron mold—good.

No. 6. 87.15 copper, 12.73 tin. In dry sand—good.

No. 7. 80.95 copper, 18.84 tin. In dry sand—bad surface. Recast in hot iron mold—good.

No. 8. 76.64 copper, 23.24 tin. In dry sand—good.

No. 9. 69.84 copper, 29.89 tin. In dry sand—good. Very weak and brittle, and broke in handling. Recast in hot iron mold—good.

No. 10. 68.58 copper, 31.26 tin. In hot iron mold—good.

No. 11. 65.34 copper, 34.47 tin. In hot iron mold—good.

No. 12. 62.31 copper, 37.35 tin. In hot iron mold—good. Broke in taking out of mold. Recast three times before getting a good casting.

No. 13. 56.70 copper, 43.17 tin. In hot iron mold—good. Broke in handling. Recast twice, breaking each time in the mold. Fourth casting good.

No. 14. 51.62 copper, 48.09 tin. In hot iron mold—good. Broke in handling, leaving piece 19 inches long sufficient for test.

No. 15. 47.61 copper, 52.14 tin; to No. 23. 15.08 copper, 84.62 tin, inclusive. In hot iron molds—first castings good.

No. 24. 11.49 copper, 88.47 tin. In hot iron mold. Bottom of mold not well stoppered, and part of metal ran out. Recast—good.

No. 25. 8.57 copper, 91.39 tin. In hot iron mold. Ran out of bottom of mold. Recast—good.

No. 26. 3.72 copper, 96.31 tin. In hot iron mold—good.
No. 27. 0.74 copper, 99.02 tin. In hot iron mold—good.
No. 28. 0.32 copper, 99.46 tin. In hot iron mold—good.
No. 29. All tin. In cold iron mold—surface irregular. Recast in cold iron mold with like result. In hot iron mold broke, apparently by shrinkage. Recast several times in hot mold before getting a good bar.

After casting, the bars were finished to a rectangular section by chipping and filing, and the more brittle bars by grinding with an emery-wheel.

EXTERNAL APPEARANCE OF THE BARS.

Much could be learned from the appearance of the bars after casting, both of their properties and of their probable behavior under test. The following were characteristic features:

(1) A regular gradation in color took place from bar No. 1, all copper, down to No. 8, 76.64 copper, 23.24 tin, the polished surface of which latter was light golden yellow. There was a regular gradation in hardness, the No. 8 being filed with great difficulty.

(2) A sudden change of color and of all properties took place at bar No. 9—69.84 copper, 29.89 tin. This bar was silver white in color, and so hard that it could not be touched with a file. Pieces broken off showed a smooth, curved or conchoidal fracture. No. 10—68.58 copper, 31.26 tin—was almost exactly similar to No. 9, and No. 11—65.34 copper, 34.47 tin—but little different.

(3) Another change of color and properties at No. 12—62.31 copper, 37.35 tin—which bar was of a dark bluish gray color, and the fracture somewhat similar to that of a piece of granite or other hard rock. This was the most dense alloy of the series, as shown in the table of specific gravities. No. 13—56.70 copper, 43.17 tin—was similar to No. 12, but lighter in color and a little softer.

(4) Bar No. 14—51.62 copper, 48.09 tin—was peculiar in showing a marked difference of color and of other properties in the two ends of the bar. The upper end was precisely like bar No. 12, while the bottom was of a much lighter color, granular fracture, and was so soft that it could be cut with a knife like a piece of chalk or soapstone.

(5) A change of properties between bars No. 14 and No. 20—25.85 copper, 73.80 tin—occurred gradually, the bars becoming whiter and softer, and the appearance of fracture changing from rough and stony-like to crystalline or granular. No. 20 could be cut with a knife, giving a short chip which had slight cohesion. From No. 20 to No. 29 (all tin) the softness increased gradually, No. 21 giving a malleable chip on being cut. From No. 24 to No. 29 the appearance of all the bars was very much the same, differing slightly in hardness, and scarcely at all in color.

From these appearances it would have at once been conjectured that bars No. 1 to No. 8 were the only ones likely to prove of value where strength was required, and that bars No. 9 to No. 18, inclusive, were deficient in ductility as well as in strength, and for all practical purposes (except, perhaps, the extremely limited use for special purposes, as speculum metal) absolutely worthless.

Nearly all of the bars appeared to be good castings, except the following: No. 1, all copper, had several blow-holes in the upper surface, chiefly at the upper end; No. 2—97.89 copper, 1.90 tin—had a large cavity in the bottom end of the bar, about 2 inches long and varying from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter; No. 21—23.35 copper, 76.29 tin—had a blow-hole or cavity extending the whole length of the bar, except 5 inches of the upper end.

Its diameter was afterward found to vary from $\frac{1}{8}$ inch to nearly $\frac{1}{2}$ inch in different parts of the bar. This was a peculiar case, and nothing resembling it was met with in bars of different compositions.

TRANSVERSE TESTS.

Tests of the first series by transverse stress were made with dead weights on an apparatus built for the purpose, a sketch of which is shown below.

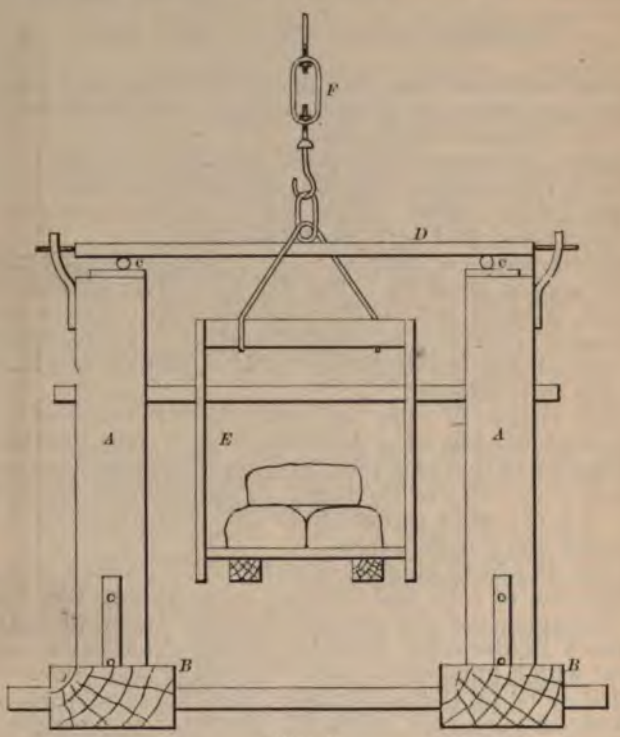

Fig. I.

A A, are two vertical pieces of timber firmly braced to base pieces B B. Two flat steel plates are fastened on the top of the vertical timbers and their upper surfaces made perfectly level. Two steel mandrels, *c c*, $1\frac{1}{4}$ inches in diameter, rest on these plates and support the bar to be tested, D. The weights are placed on the tray E, which hangs from a third mandrel resting on the upper edge of the bar at its center. The tray, with the weights and mandrel, may all be raised at once by a differential pulley. In lowering, the pulley is used till the mandrel nearly touches the bar, when the turnbuckle F is employed to complete the operation gradually and without shock.

In testing the bars by means of this apparatus, fine lines were scored on each bar to indicate the position of the center and of the points of support. The latter were 22 inches apart and equidistant from the center. The mandrels, *c c*, were then placed on the flat steel plates, and held at the distance of 22 inches apart between centers, by calipers made for the purpose, and the bar placed on the mandrels, with the lines marked for the points of support directly above the centers of the

mandrels. The tray and its attachments weighing 35 pounds, all weights less than this in amount were hung directly on the center of the bar by means of a hook bearing on its upper surface. When the tray was used it was lowered very gradually by means of the differential pulley and the turnbuckle, and additional weights placed on the bottom of the tray, care being taken to keep the center of gravity of tray and weights always as nearly as possible directly under the center of the bar.

The deflections and sets produced by the applied loads were measured by means of a Salleron's cathetometer, which gave readings to $\frac{1}{50}$th of a millimeter, or $\frac{1}{1270}$th of an inch. This instrument is shown in the accompanying cut.

Fig. 2.

The observations were made by noting through the telescope a fine dot made on a piece of white paper glued to the center of the bar. The cross-hairs of the telescope were caused to bisect this dot, and the error of observation was not larger than one division of the vernier.

The tables of results seem to indicate that the sum of all errors of observation and of the instrument might sometimes reach as high as $\frac{1}{10}$th of a millimeter when reading sets, but was always less than this when reading deflections.

While raising and lowering the weights to take readings of sets, the bar was prevented from rolling on the mandrels by two small pins, which were held by brackets on the upright timbers of the apparatus, and just brought in contact with each end of the bar. The slightest change of position could at once be detected by the observer at the telescope of the cathetometer.

Complete tables of the results of these tests are appended. A condensed summary of results is given below. In these appended tables are given the results of every test that was made. In tables giving summaries and averages of results, and in curves and in deductions made from them, all tests which are considered unsatisfactory by reason of imperfections in the piece tested or other causes are rejected, and only those tests which were made with sound test specimens are retained.

TABLE II.—*First Series Alloys of Copper and Tin.*

Tests by Transverse Stress.

No.	Mean composition by analysis.		Length between supports.	Breadth.	Depth.	Breaking-load.	Modulus of rupture. $R=\frac{3}{2}\frac{l}{b\,d^2}(P+3)$	Total deflection.	Limit of elasticity.		First set of 0.01 inch.		Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,b\,d^3}(P+4)$		
	Copper.	Tin.	l	b	d	P		Δ	Load. P_1	Corresponding value of $R_1=\frac{l}{b\,d^2}(P_1+3)$	Load. P_2	Corresponding value of $R_2=\frac{l}{b\,d^2}(P_2+3)$	P	Δ	E
			Inches.	*Inches.*	*Inches.*	*Pounds.*		*Inches.*	*Lbs.*		*Lbs.*		*Pounds.*	*Inches.*	
1	Cast copper	.....	22	0.994	1.010	650	21,251	2.306	225	7,420	250	8,234	200	0.038	13,986,605
2	97.89	1.90	22	1.011	1.005	550	.....	4.561 +	175	5,753	200	6,561	175	0.041	11,324,079
3	96.06	3.76	22	1.000	0.998	1,000	33,232	7.634 +	350	11,696	400	13,352	350	0.069	13,739,654
4	92.11	7.80	22	0.997	1.012	1,350	43,731	6.706 +	575	18,682	600	19,450	450	0.082	14,263,420
5	90.27	9.58	22	1.008	0.993	1,485	49,400	7.534 +	600	20,019	600	20,019	500 − 100	0.077	14,012,135
6	87.15	12.73	22	0.996	1.003	1,050	34,531	2.291 +	300	9,936	400	13,216	200	0.051	10,532,146
7	80.95	18.84	22	0.998	1.011	1,750	56,715	0.492	1,150	37,303	900	29,215	1,100 − 100	0.194	13,304,198
8	76.63	23.24	22	0.998	1.002	975	32,210	0.191	975	32,210	975	32,210	950 − 100	0.167	13,495,122
9	69.84	29.88	22	0.992	1.000	360	12,076	0.062	360	12,076	360	12,076	350	0.062	15,321,736
10	68.58	31.26	22	0.990	1.004	275	9,152	0.043	275	9,192	275	9,192	250	0.048	15,694,556
11	65.63	34.47	22	0.982	1.003	140	4,776	0.020	140	4,776	140	4,776	140	0.020	19,344,368
12	64.31	37.35	22	0.992	1.000	80	2,761	0.032	80	2,761	80	2,761	30	0.0095	9,603,989
13	56.70	43.17	22	0.998	0.990	60	2,126	0.103	60	2,126	60	2,126	50	0.0103	14,693,513
14	51.62	48.09	17½	1.005	0.992	140	3,877	0.040	140	3,877	140	3,877	60	0.018	5,174,546
15	47.61	52.14	22	0.990	1.000	105	3,600	0.019	105	3,600	105	3,600	50	0.0087	17,039,130
16	44.52	55.28	22	1.000	0.994	140	4,776	0.026	140	4,776	140	4,776	50	0.0087	16,823,869
17	42.38	57.30	22	1.002	0.991	210	7,172	0.042	210	7,172	210	7,172	140	0.017	23,238,907
18	38.37	61.34	22	0.988	1.003	250	8,400	0.060	250	8,400	250	8,400	125	0.028	12,302,353
19	34.22	65.80	22	0.991	1.004	160	5,384	0.043	160	3,414	130	4,393	100	0.025	11,041,901
20	25.85	73.80	22	0.990	1.002	240	8,067	0.121	140	4,747	120	4,083	40	0.012	9,982,832
21	23.35	76.29	22	1.002	0.995	370	12,408	0.269	140	4,471	150	4,784	40	0.0103	11,520,264
22	20.25	79.63	22	0.988	1.005	300	10,019	0.345	100	3,334	100	3,334	25	0.0095	9,743,644
23	15.08	84.62	22	1.004	0.995	270	9,063	0.858	60	2,091	50	1,759	25	0.0111	7,032,130
24	11.49	88.47	22	0.973	0.980	300	10,706	5.849	75	2,756	85	3,109	30	0.0095	10,403,101
25	8.57	91.39	22	1.002	1.006	160	5,305	8.000 +	40	1,399	60	2,050	25	0.0095	7,965,988
26	3.72	96.31	22	1.005	1.005	210	6,925	8.000 +	40	1,398	60	2,048	30	0.0103	8,613,200
27	0.74	99.02	22	1.000	1.012	120	3,964	8.318	40	1,386	50	1,708	25	0.011	6,771,517
28	0.32	99.46	22	0.989	1.000	130	4,438	8.114	40	1,435	70	2,436	40	0.0126	9,398,659
29	.....	Cast tin	22	0.993	1.002	110	3,740	8.305	30	1,092	40	1,423	20	0.0095	6,734,838
30	Cast copper	.....	22	0.990	0.980	860	29,848	8.000 +	120	4,254	160	5,638	80	0.0224	10,203,205

Remarks.—No. 1. Defective, full of blow-holes; fourth casting. No. 2. Defective, full of blow-holes; bent; first casting; sand mold. No. 3. Bent; second casting; iron mold. No. 4. Bent; second casting; iron mold. No. 5. Bent; first casting; iron mold. No. 6. Defective, not homogeneous; first casting; iron mold. No. 14. Short bar and much liquated. No. 17. Liquated. Nos. 26, 27, 28, 29, and 30, bent.

NOTES ON THE TESTS BY TRANSVERSE STRESS.

Bar No. 1, all copper, proving to be a bad sample of cast copper, another bar was made, No. 30, which gave much better results. The great differences in the behavior of these two bars will be referred to at some length further on.

In the appended tables, in the column headed "Load," the figures represent the weights applied to the bar.

The formula for deflection of long bars tested by transverse stress, within the elastic limit, is given by writers on resistance of materials as

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3} + \frac{5}{8}\,W\,\frac{l^3}{4\,E\,b\,d^3},$$

where Δ is the deflection, P the applied load, W the weight of the bar between supports, E the coefficient (or, as generally termed, the modulus) of elasticity,* l, b, and d the length between supports, breadth and depth of the bar. As the weight of the bar between supports in these tests was from 6 to 7 pounds, 4 pounds may be substituted for $\frac{5}{8}$ W, and the formula becomes—

$$\Delta = \frac{l^3}{4\,E\,b\,d^3}\,(P + 4 \text{ pounds}),$$

whence—

$$E = \frac{l^3}{4\,\Delta\,b\,d^3}\,(P + 4 \text{ pounds}),$$

from which latter formula the moduli of elasticity given in the tables of tests of each bar were calculated.

It will be observed in these last tables that in many of them, especially in tests of the stronger metals, the modulus of elasticity increases slightly

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* The modulus of elasticity is a value which expresses the relation between the extension, compression, or other deformation of a bar, and the force which produces the deformation. In tensile stress it is the load per unit of sectional area divided by the extension per unit of length. In transverse tests it is obtained from the formula given above. The value of E found by tests by tensile stress is said to be the same as that obtained by transverse tests of long bars. The formula given above for deflection of bars tested by transverse stress, viz:

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3},$$

is not quite accurate, as it neglects the deflection due to shearing stress, which varies directly as the load. The true formula (the weight of the bar itself not being considered) is—

$$\Delta = \frac{P\,l^3}{4\,E\,b\,d^3} + \frac{P\,l}{4\,E_s\,b\,d},$$

in which E_s is the coefficient of elastic resistance to shearing.

In the tests herein described, l, in general, is 22 inches; b and d are each nearly one inch. The formula then reduces approximately to

$$\Delta = \frac{10648\,P}{4\,E} + \frac{22\,P}{4\,E_s}.$$

The value of E_s is shown (see Wood's "Resistance of Materials") never to be greater than $\frac{2}{5}$ E, which would make the last term of the above equation

$$\frac{2 \times 22}{5 \times 4\,E} = \frac{44}{20\,E},$$

which is only $\frac{1}{1\,\frac{1}{2}\,\frac{1}{0}}$ of the first term of the second member of the equation. The resistance to shearing may therefore be neglected in calculating the modulus of elasticity from transverse tests of bars 22 inches long, as the error thereby introduced is less than one-tenth of 1 per cent. The error is much larger, however, with shorter bars.

at the beginning of the test, then remains nearly constant for a certain distance, or slowly approaches a maximum; and then, at first slowly and afterward very rapidly, decreases to the breaking point. This corresponds with what is shown in the plotted curve of deflections, viz, the beginning of the curve sometimes shows a slight curvature convex to the axis of abscissas, then a straight line slightly inclined from the vertical. The inclination from the vertical then increases, at first slowly and afterward more rapidly, till the curve takes a more nearly horizontal direction.

In the table given above, the figures in the column headed "Modulus of elasticity" are those which are considered the *most probable* moduli within the elastic limit, or which most nearly represent the relation between the stresses and the distortions within that limit. In most cases the maximum modulus given in the tables of tests of each bar is selected, unless the deflection corresponding to the maximum is so small a quantity as to render the probable error of the observation a large portion of the apparent deflection.

In a few instances the apparent modulus at the beginning of the test is much smaller than it soon afterward becomes; and this indicates a possible error of the observations at this part of the test. The moduli of these bars, given in the above table, are therefore determined by rejecting the deflections at the beginning of the test, and taking the ratio of distortion to stress at a point where this ratio becomes sensibly constant.

In the column headed "Modulus of elasticity," the figures of deflections and loads corresponding to the assumed most probable moduli are given. The tests in which the first portion was rejected in obtaining the modulus are indicated in the figures of load by giving the limits between which the modulus is taken.

The modulus of rupture* is found from the formula

$$R = \frac{3}{2}\frac{l}{b d^2}\left(P + \frac{1}{2}W\right)$$

where P is the applied load causing fracture, W the weight of the bar between the supports, and l, b, and d length, breadth, and depth as before.

Substituting an approximate value for the weight of the bar, we have

$$R = \frac{3}{2}\frac{l}{b d^2}\left(P + 3\right)$$

where P is the applied load.

* The modulus of rupture is defined by some writers as "the strain at the instant of rupture upon a unit of the section which is most remote from the neutral axis on the side which first ruptures" (Wood's Resistance of Materials, ii edit., 1875, p. 79). It is used here as a means of comparing the transverse strength of bars of different breadths and depths, the strength of bars tested by transverse stress varying directly as the load, directly as the length, and inversely as the breadth and the square of the depth, or in cases of bars supported at both ends and loaded in the middle, as expressed by the formula

$$R = \frac{3}{2}\frac{Pl}{b d^2}.$$

If the dimensions are all reduced to unity, the formula becomes

$$R = \frac{3}{2}P.$$

In other words, the modulus of rupture is a value which is proportional to the transverse strength of a bar, and is theoretically equivalent to one and a half times the load which would break a bar one unit in length, in breadth, and in depth, supported at both ends and loaded in the middle.

The more ductile bars, as seen in the tables of tests, bent without breaking. The correct modulus of rupture in these cases, therefore, could not be determined, and it was necessary to assume a given amount of bending as equivalent to breaking the bar or rendering it useless. This was taken at a deflection (while the load rested on the bar) of $3\frac{1}{2}$ inches, and the modulus of rupture is calculated from the load causing this maximum deflection, as affording a means of comparing the transverse strengths of all the ductile bars which were tested.

The limit of elasticity is taken to be the point at which the deflections begin (usually suddenly) to increase in a greater ratio than the applied loads, and in the plotted curves of deflections it is the point at which the curve begins to diverge from its original and nearly vertical direction and becomes nearly horizontal.

This point is not always clearly defined, and it is difficult to fix its exact position.

The limit of elasticity coincides in some, though not in all, cases with the first observed set or point at which the bar under test exhibits a deflection after the load is removed.

The point of "first appreciable set" given in the tables is taken as a set of 0.01 inch, which is an amount much beyond the limits of error of observation.

For the purpose of comparing the resistances of the different bars to stress at the elastic limit and at the first appreciable set, with their resistances at the points of final rupture, values of

$$R_1 = \frac{3\ P_1\ l}{2\ b\ d^2}$$

are taken, in which P_1 is the load corresponding to the limit of elasticity or to appreciable set.

BEHAVIOR OF THE BARS UNDER STRESS.

A glance at the table of results given above shows that from bar No. 1 (all copper) to bar No. 7—80.95 copper, 18.84 tin—inclusive, there was a gradual increase of strength, except in the cases of bars No. 2 (97.89 copper, 1.90 tin) and No. 6 (87.15 copper, 12.73 tin), which were defective. Bars No. 2 to No. 5 (1.90 tin to 9.58 tin) showed great ductility as well as strength, as deflections exceeding $4\frac{1}{2}$ inches were given them without breaking. Bar No. 1 (all copper) broke after a deflection of 2.306 inches, while bar No. 30, also copper, bent (as shown in the appendix) to about 8 inches before breaking, showing a marked difference in ductility as well as in strength. This was due probably to oxidation of the copper in bar No. 1 by repeated melting and casting.

Bar No. 7 (80.95 copper, 18.84 tin), the strongest of the series, showed comparatively little ductility, breaking after a deflection of little over half an inch. From No. 8 to No. 13 (23.24 to 43.17 tin) inclusive, there is a regular and very rapid decrease both in strength and ductility, the latter being the weakest bar of the series, showing only about $\frac{1}{27}$th of the strength of No. 7 and a deflection of only 0.0103 inch. As before stated, this bar gave great trouble in casting by breaking in the mold. Bar No. 9 (69.84 copper, 29.89 tin) which, in appearance, also differed remarkably from No. 8 (76.64 copper, 23.24 tin), had less than $\frac{2}{3}$ of its strength and less than $\frac{1}{4}$ of the strength of No. 7, which latter differed only 10 per cent. from it in composition by original mixture or 11 per cent. by analysis. Bars No. 14 to No. 20 (48.09 to 73.80 tin) inclusive, show a somewhat irregular variation in strength and ductility, but all of them

are worthless as regards either of these qualities, the best having only about $\frac{1}{7}$th of the strength of the maximum, and a deflection of only 0.123 inch before breaking. Bar No. 21 (23.35 copper, 76.29 tin) shows considerably greater strength and ductility than any of the series between No. 8 and No. 20, and greater strength than any from No. 8 to No. 29 (all tin), thus giving what may be called a second maximum point of strength in the series. This bar had a cavity extending throughout nearly its whole length.

No. 21 to No. 24 (76.29 to 88.47 tin) have much higher strength than those above and below them in series, showing that the second maximum point of strength is approached by bars having a difference of over 10 per cent. in composition. From No. 25 to No. 29 (91.39 to 100 tin) there is a somewhat irregular decrease of strength but a very great increase of ductility, bar No. 29 (all tin) showing the maximum ductility of the series and a second minimum of strength. Bars No. 26 to No. 29 inclusive bent without breaking, as did those from No. 2 to No. 6 (1.90 to 12.73 tin), at the other end of the series.

With reference to the relation of the elastic limit to the ultimate transverse resistance, it will be seen that from bar No. 1 to No. 7 inclusive the elastic limit occurred at from 35 to 65 per cent. of the ultimate resistance. At No. 8 the limit of elasticity approached nearly if not quite the ultimate resistance; and from No. 9 to No. 18 (29.89 to 61.32 tin) inclusive the two coincided, *i. e.*, the elastic limit was not reached till the bar broke. From No. 19 (34.22 copper, 65.80 tin) to the end of the series (all tin) the elastic limit was again reached before fracture, the ratio decreasing to No. 22 (20.25 copper, 79.63 tin), and then remaining appreciably constant at from 20 to 30 per cent. to the end of the series.

By this table, therefore, the relation which the composition bears to the mechanical properties of strength, ductility, and elastic resistance is defined with tolerable exactness.

It is seen that bars from No. 1 to No. 8, inclusive, have considerable strength, and that all the rest are practically worthless for all purposes where strength is required. The dividing line between the strong and the brittle alloys is precisely that at which the color changes from golden yellow to silver white, viz., at a composition containing between 24 and 30 per cent. of tin; alloys containing more than 24 per cent. tin are comparatively valueless.

Referring to Tables ——, which are appended, a short account of the behavior of each bar will now be given.

Bar No. 1 (cast copper).—Weights were applied, one pound at a time, until 7 pounds were reached (11 pounds, including the effective weight of the bar), when the first deflection was observed, 0.004 inch. The load was then increased 5 or 10 pounds at a time until 100 pounds were reached; after each increase and the reading of the corresponding deflection, the load was all removed and a reading of the set taken. After 100 pounds each increase was made 25 pounds, removing the load and reading the set each time after reading the deflection. A set of 0.0016 inch was observed when the load of 12 pounds was removed, but as readings of sets up to 225 pounds were irregular and never exceeded 0.007 inch, these readings may be erroneous, the error being due to a combination of several causes, viz., personal errors of observation of the bisection of the cross-hairs in the telescope of the dot observed by it, and of the reading of the vernier; slight lateral shifting of the bar on the rollers, and a slight compression of the skin of the bar at the points which touched the rollers. The first three errors named would not amount to more than 0.001 inch each, and might either increase or de-

crease the reading. The last would act only to increase the reading, and would vary in amount with the condition of the surface resting on the rollers, the rougher the surface the greater the amount of compression by the rollers. This error could be eliminated only by polishing the bars at the points which rested on the rollers and taking all precautions to insure a perfectly fair bearing. It would increase the apparent deflections by about the same quantity by which the sets were increased, and this may account for the fact that the apparent deflections at the beginning of a test often bear a greater ratio to the applied load than at a subsequent stage of the test, thus showing an apparently lower modulus of elasticity at the beginning of the test than just before reaching the elastic limit.

The sum of these errors possibly amounting to 0.007 inch, the point which has been taken as a standard of comparison of "first appreciable set" of the different bars is a set of 0.01 inch. In bar No. 1 this amount of set took place after the application and removal of the load of 250 pounds. The elastic limit is taken at 225 pounds, this being the point where the deflections evidently begin to increase in a greater ratio than the applied loads. At 450 pounds the deflection of the bar was observed to increase slightly as the load was left on for five minutes, and the same phenomenon was again observed at 600 pounds. An increase of deflection was observed on the second application of every load after 400 pounds. Except where otherwise stated, in this and in all other tests, the load was left on the bar only long enough for a reading to be taken, and the repetition of the observation to insure correctness, the time required being from one to two minutes.

After 650 pounds had been placed on the bar, and then removed and the reading of the set taken, a small crack was discovered on the under side of the bar, near the middle, and, on gradually replacing the weight of 549 pounds, the bar broke. The fracture showed the bar to be a poor one, being spongy and full of blow-holes, the largest of which was $\frac{1}{4}$ inch in diameter.*

An analysis was made of the turnings of this bar and also of bar No. 30 for the purpose of learning whether the chemical composition would throw any light upon the causes of the presence of the blow-holes and the lack of ductility of this bar as compared with that of other bars subsequently tested.

The result was the discovery of an extraordinary amount of suboxide of copper in bar No. 1. This was no doubt formed in the repeated meltings which the bar had undergone.

The following are the analyses:

	No. 1.	No. 30.
	Per cent.	*Per cent.*
Metallic iron	0.020	0.014
Metallic zinc	0.014	0.057
Metallic silver	0.035	0.014
Metallic arsenic	none	none
Metallic antimony	none	none
Metallic tin	none	.....
Metallic bismuth	none	none
Metallic lead	trace	trace
Metallic copper	87.900	96.339
Suboxide of copper	12.086	3.580
Carbon	none	.....
	100.055	99.995

A graphic representation of the test of this and other bars is given on Plate No. XVI. The curves graphically representing these tests exhibit the relative behavior of each bar much better than the tables.

Bar No. 2 (97.89 copper, 1.90 tin).—This bar was tested in the same

* See account of bar No. 30 for a test of a good bar of copper.

manner as No. 1 but with less frequent readings of sets, only two being made before 200 pounds was placed on the bar; these readings showed no set. At 200 pounds a set of nearly 0.01 inch was observed. The deflections begin to increase more rapidly than the loads after reaching 175 pounds, which load is taken as at the elastic limit. At 275 pounds the bar was noticed to sink slowly after the load was applied, but the load was increased without stopping. At 375 pounds the bar appeared to sink quite rapidly. At 475, 500, and 550 pounds the load was left on the bar 3, 10 and 3 minutes respectively, producing a large increase of deflection each time. At 575 pounds the bar bent rapidly and slid through between the supports. As a deflection of 3½ inches was caused by the load of 550 pounds, this is considered as the breaking weight, from which the modulus of rupture is calculated.

The bar was finally broken by bending alternately in contrary directions, and the principal cause of its weakness in comparison with the copper bar was found to be its spongy structure.

A vast number of very minute blow-holes, almost microscopic in size, were found. Further tests on pieces of this bar showed this structure throughout all the upper portion of the bar, but the lower portion was much more compact. As this structure may probably be due to accidental causes, and not inseparable from its composition, the strength shown by this particular bar is thought to be beneath that which may be expected from other bars of the same composition, and hence the bar is not given in the curve showing the relation of transverse strength to composition, Plate I. The modulus of elasticity is less than that of any other bar from No. 1 to No. 6.

Bar No. 3 (96.06 copper, 3.76 tin).—This bar proved to be much stronger than either of the preceding. A set of 0.01 inch took place at 400 pounds, and the limit of elasticity is considered to have been reached at 350 pounds. At 600 pounds the bar was observed to sink while under stress, and it was left for 50 minutes, the deflection increasing during that time from 0.181 to 0.252 inch; the rate of increase of deflection gradually diminishing, the first 10 minutes showing an increase of 0.048 inch, the next 20 minutes 0.015 inch, and the next 20 minutes 0.008 inch. The same phenomenon was noticed several times during the test, the bar once being left under stress of 850 pounds for 15 hours 45 minutes, the last 15 hours of the time showing a much less increase of deflection than the first five minutes.

From the test of this bar, and others in like manner, it appears that the increase of deflection finally ceases, provided the load is not greater than a certain limit for each bar. When the load is too great a still more curious phenomenon is observed, as in the case of the bar in question when a load of 1,000 pounds was placed on it, viz, the decrease of the rate of increase of deflection, and again after a certain time the increase of this rate till the bar finally breaks down. In this case the increase of deflection with the first five minutes was 0.422 inch, in the next five minutes 0.120 inch, showing a decreasing rate; in the next 30 minutes 0.442 inch, showing a slight increase of the rate, and in the next 30 minutes 3.532 inches, showing a very rapid increase. At this point the bar had a deflection of 7.634 inches and the tray reached the base of its supports, thus ending the test. On breaking this bar, the fracture showed a homogeneous metal free from blow-holes.

Bar No 4 (92.11 copper, 7.80 tin).—A set of 0.01 inch was reached at 600 pounds, and the elastic limit at 575 pounds. The effect of allowing the load to remain on the bar was observed several times after 950 pounds had been reached, with similar results to those indicated when

describing the behavior of bar No. 3. At 1,350 pounds the deflection increased in 30 minutes from 3.226 inches to 6.706 inches, when the bar slid through between the supports. On breaking the bar, after bending in contrary directions, the fracture showed a compact-looking metal, of an earthy appearance, with scarcely any luster, and with only a few very small blow-holes. The color was not entirely homogeneous, some parts being more grayish than others, the general color being reddish yellow.

Bar No. 5 (90.27 copper, 9.58 tin).—A set of 0.01 inch was reached at 600 pounds, and the elastic limit at the same point. Time-tests were made after 950 pounds were applied, but in no case was a load left longer than 15 minutes. The behavior of this bar was very similar to that of bar No. 4, the deflections corresponding to the various loads being nearly the same for each bar. Its ultimate strength, however, was greater, 1,485 pounds being required to give it a deflection of 3½ inches, the same increasing the deflection in 13 minutes, to 7.534 inches, causing the tray to reach the base of its supports. In breaking the bar, it was first bent by pressure until the two ends touched, and then bent in a reverse direction, but broke before being straightened. The fracture showed a dense, compact metal, but not entirely homogeneous in color or structure. There were a few small blow-holes, and the lower part of the fracture was of a dull, earthy appearance, with portions of a fibrous appearance. The color was dull reddish-yellow, except a distinctly large spot in the center of a very dark red (darker than copper) and a few small yellow spots. This metal, although stronger than any of the bars previously tested, is probably not so strong as it might have been had it been homogeneous.

Bar No. 6 (87.15 copper, 12.73 tin).—A set of 0.01 inch was reached at 400 pounds and elastic limit at 300. A few "time-tests" were made, showing increase of deflection under constant load after 700 pounds. The bar proved to be much weaker than the two which preceded it, and broke at 1,050 pounds. The cause of the weakness was at once shown by the appearance of the fracture. Two distinct colors were seen, golden-yellow and silver-gray, finely mottled together over the whole surface of the fracture, indicating that liquation or an imperfect mixture of the two metals had taken place, and that the two colors were probably those of two distinct alloys, intimately mixed. The modulus of elasticity, as well as the limit of elasticity, and the ultimate strength of this bar are very low, and as the bar is considered a defective one, like bar No. 2 (97.89 copper, 1.90 tin), the results are omitted in constructing curves. It will be observed that the modulus of elasticity is less than that of any bar from No. 1 to No. 11 (all copper, to 65.34 copper, 34.47 tin).

Bar No. 7 (80.95 copper, 18.84 tin).—This bar proved to be the strongest of the series. A set amounting to 0.01 inch was not detected until 900 pounds had been placed on the bar, and this was increased only to 0.016 inch at 1,200 pounds. The limit of elasticity appears to be passed at 1,150 pounds. The load of 1,750 pounds was allowed to remain on the bar for 15 hours, during which time the deflection increased 0.027 inch. At the end of the 15 hours the load was removed and a reading of the set taken. The load was then replaced gradually, the last portion of the 1,750 pounds being replaced, a pound at a time. The last pound had been replaced, and the reading of the deflection was about to be made, when the bar suddenly broke at a point 2 inches from the middle. The fracture showed a close, compact structure, and a reddish or pinkish gray color, entirely different from that of any of the bars previously tested. Although this bar is the strongest of the series, it has much

less power to resist sudden shocks, in consequence of its lack of ductility, the maximum deflection being only 0.537 inch.

Bar No. 8 (76.64 copper, 23.24 tin).—The behavior of this bar was similar to that of No. 7, but it was much weaker and had much less ductility, breaking with the load of 975 pounds, and showing a maximum deflection of but 0.191 inch. No set amounting to 0.01 inch was found, the greatest being 0.0055 inch at 900 pounds. The elastic limit was apparently not reached till fracture took place, the ratio of deflection to the loads remaining constant throughout the whole test. The fracture showed a metal somewhat similar to No. 7, but lighter in color.

Bar No. 9 (69.84 copper, 29.89 tin).—This bar showed great lack of both strength and ductility, breaking at 360 pounds after a deflection of 0.062 inch. As with bar No. 8, no set amounting to 0.01 inch could be detected, and the elastic limit was not reached till fracture took place. The fracture showed a metal of an entirely different character from any of those previously tested, almost as brittle as glass, with a vitreous appearance and brilliant luster, almost silver-white in color, with no indication of the presence of copper which formed 70 per cent. of its weight. The shape of the fracture was peculiar; a side view of it is shown below.

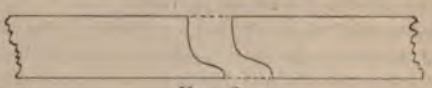

FIG. 3.

Bar No. 10 (68.58 copper, 31.26 tin).—This bar was almost precisely similar in appearance and action under test to bar No. 9, but showed a still less degree of strength and ductility, breaking at 275 pounds, after a deflection of 0.043 inch. As in the case of bar No. 9, no set of 0.01 inch and no elastic limit were reached before fracture.

Bar No. 11 (65.34 copper, 34.47 tin).—This bar exhibited still less strength and ductility than either of the preceding, breaking at 140 pounds, after a deflection of 0.02 inch, showing no set and no elastic limit before fracture. The structure as shown by the fracture was quite different from those of bars No. 8 and No. 9, being rough granular instead of vitreous. The modulus of elasticity increases from the beginning to the end of the test, reaching a much higher figure than any of the preceding bars.

Bar No. 12 (62.31 copper, 37.35 tin) was still more brittle and weaker than No. 11. It broke at 80 pounds, after a deflection of 0.032 inch. A set of 0.103 inch was observed at 70 pounds, but no limit of elasticity was detected. The fracture showed a metal of much darker color than No. 11, and of an appearance somewhat like stone. This metal had a greater specific gravity than any other in the series. Its modulus of elasticity is less than one-half of that of bar No. 11.

Bar No. 13 (56.70 copper, 43.17 tin).—The weakest and most brittle of the series, breaking at 60 pounds, after a deflection of only 0.0103 inch, with no apparent set and no elastic limit before fracture. The appearance of the fractured metal was somewhat similar to that of No. 12, but lighter in color.

Bar No. 14 (51.62 copper, 48.09 tin).—This bar was shorter than the rest of the bars of the series, its length between supports being 17½ inches. It proved to be somewhat stronger than No. 13, breaking at 140 pounds, after a deflection of 0.040 inch. A set of 0.01 inch was observed at 65 pounds, but it had increased only to 0.019 at 130 pounds, and no elastic limit was reached before fracture. This bar showed a dif-

ference of structure and color at the two ends, due to liquation or separation of the metals into distinct alloys; the chemical analyses of samples taken from the two ends showed a difference of composition of more than 10 per cent. The modulus of elasticity is exceptionally low. This may possibly be due to errors of observation of deflection.

Bar No. 15 (47.61 copper, 52.14 tin).—Broke at 105 pounds after a deflection of 0.019 inch. No set was detected, and no limit of elasticity before fracture.

Bar No. 16 (44.52 copper, 55.28 tin).

Bar No. 17 (42.38 copper, 57.30 tin).

Bar No. 18 (38.37 copper, 61.32 tin).

These three bars were all similar in behavior to No. 15, very weak and brittle, giving no sets amounting to 0.01 inch, and no elastic limits before fracture. No. 17 gave a modulus of elasticity much higher than any other bar of the series.

Bar No. 19 (34.22 copper, 65.80 tin).—This was similar to the four preceding bars, but took a set of 0.0118 inch at 130 pounds. The position of the elastic limit is very doubtful, but it appears to have been passed at 100 pounds. The modulus of elasticity is less than half of that of No. 17. It appears that the modulus decreases from this bar to the end of the series, but with considerable irregularity.

Bar No. 20 (25.85 copper, 73.80 tin).—Weak and brittle like No. 19, but had a slightly greater ductility, showing a deflection of 0.121 inch before breaking, and a set of 0.01 inch at 120 pounds. It broke at 240 pounds, and the elastic limit appears to have been passed at about 140 pounds. The color and appearance of the fracture were similar to those of the five preceding bars. The modulus of elasticity is highest at the beginning of the test, and rapidly decreases from the beginning to the end. This is common to all the bars from No. 20 to No. 29 inclusive, and is characteristic of all the ductile metals which have no well-defined limit of elasticity. The moduli of these bars, given in the above table of results, are in general those corresponding to deflections of 0.01 inch.

Bar No. 21 (23.35 copper, 76.29 tin).—This bar was remarkable in having a hole extending from the bottom throughout nearly its whole length. The hole varied in size and shape in different parts of the bar. At the point of fracture, it was nearly circular in section, about $\frac{1}{4}$ inch in diameter, and nearly in the center of the section. Notwithstanding the presence of this cavity, the bar proved to be stronger than any of the bars from No. 9 to No. 29. It broke at 370 pounds, after a deflection of 0.269 inch. A set of 0.01 inch was reached at 150 pounds, and the elastic limit was reached at 140 pounds. The fracture showed a light-gray, fine granular appearance, slightly darker than No. 20.

Bar No. 22 (20.25 copper, 79.63 tin).—This bar was somewhat weaker than No. 21, but more ductile, breaking at 300 pounds, after a deflection of 0.345 inch. The load of 100 pounds produced a set of 0.118 inch, and the elastic limit was reached at the same load. The fracture showed a coarse granular, crystalline structure and a very light gray color.

Bar No. 23 (15.08 copper, 84.62 tin) was weaker and more ductile than No. 22. It broke at 270 pounds, after a deflection of 0.858 inch. A load of 50 pounds produced a set of 0.0095 inch, and the elastic limit was reached at 60 pounds. "Time-tests," lasting one and two minutes, were made at various loads greater than 170 pounds, showing increase of deflection with each test. The fracture was light grayish-white, with large crystalline structure, almost precisely similar in appearance to No. 19, which varied from it in composition more than 20 per cent.

Bar No. 24 (11.49 copper, 88.47 tin).—This bar was a little stronger,

and very much more ductile, than No. 23. It broke at 300 pounds, after a deflection of 5.849 inches. A set of 0.01 inch was probably given by a load of 85 pounds, the reading for 75 pounds being 0.0063 inch, and for 100 pounds 0.205 inch. The limit of elasticity appears to have been passed at 75 pounds. At 200 pounds the deflection increased in one minute from 0.341 to 0.436 inch; at 270 pounds it increased in two minutes from 0.975 to 1.502 inches, and at 290 pounds it increased in one minute from 2.128 to 2.562 inches. When 300 pounds was placed on the bar, it sank down rapidly and broke in about 20 seconds, the deflection increasing before breaking from 2.739 to 5.849 inches.

Bar No. 25 (8.57 copper, 91.39 tin).—This bar showed a less strength than No. 24, with greater ductility. It broke at 160 pounds, after being left under that stress for several hours. A set of 0.0118 inch was produced by a load of 60 pounds, and the elastic limit was apparently reached at 40 pounds. When 100 pounds was placed on the bar, the deflection was observed to increase with the time it was allowed to remain, showing an increase of deflection of 0.021 inch in 10 minutes. "Time-tests" made with the loads of 100, 120, 140, and 160 pounds with like results, 140 pounds being left on the bar for more than 40 hours, increasing the deflection from 0.221 to 1.277 inches. One hundred and sixty pounds was left on the bar for more than 50 hours, increasing the deflection from 1.294 to 5.207 inches, the rate of increase at first decreasing, then remaining constant for several hours, and finally increasing. The bar was finally left overnight, under a load of 160 pounds, with a deflection of 5.207 inches, and found broken the next morning, the bend left in the bar after breaking indicating that a deflection of nearly 8 inches had been given to the bar before fracture. The fracture showed a fine granular structure.

The records of bars No. 24 and No. 25 show that the ultimate breaking weight of such ductile metals depends in a very great degree upon the time during which they are left under stress. The duration of the test of bar No. 24 was about one hour, that of bar No. 25 was more than four days. As the breaking load of No. 25 was left on the bar for more than two days before rupture took place, it is inferred that a much greater load would have been required to break the bar in 20 seconds, the time required to break bar No. 24. In the case of bar No. 25 it would appear, from the fact that large increase of deflection was produced by various loads remaining on the bar for one or two minutes, that a much smaller load than 300 pounds would have broken the bar had it been allowed to act for a sufficient length of time.*

Bar No. 26 (3.72 copper, 96.31 tin).—This bar was apparently stronger than No. 25, very probably in consequence of the greater rapidity of the test, no load being left on the bar for a greater length of time than three minutes. A set of 0.0166 inch was produced by the load of 60 pounds, and the elastic limit appeared to have been reached at 40 pounds. At 100 pounds the deflection was greater than that of bar No. 25 with the same load, indicating it to be a weaker bar. No "time-test" was made until 200 pounds was applied. This load produced a large increase of deflection in three minutes. The bar finally bent under a load of 210 pounds, with a total deflection of nearly 8 inches, and was so ductile that it required to be cut partly through and bent repeatedly in order to break it.

Bar No. 27 (0.74 copper, 99.02 tin).—This bar was much weaker than

*These modifications in method of testing were made to secure data for other investigations by the writer. See appendix for papers by the writer, in which these phenomena are discussed at length and for strain-diagrams illustrating them.—R. H. T.

No. 26, with equal or greater ductility, taking a set of 0.02 inch at 50 pounds, reaching the elastic limit at 40 pounds, and bending to a total deflection of 8 inches at 120 pounds. Several "time-tests" were made, causing the bar to show less strength than it otherwise would have done.

Bar No. 28 (0.32 copper, 99.46 tin).—This bar proved somewhat stronger than No. 27, as the final bending load was 10 pounds greater and the "time-tests" were of much longer duration. The elastic limit was apparently reached at 40 pounds, and a set of 0.014 inch took place at 70 pounds.

Bar No. 29 (all tin).—The behavior of this bar was very similar to that of bars Nos. 26, 27, and 28, but the metal was somewhat weaker and softer. A load of 40 pounds produced a set of 0.0095 inch, and the elastic limit appeared to be reached at about 30 pounds. At 80 pounds a crack was observed on one of the edges on the under side of the bar, which gradually opened but did not increase in length. At 110 pounds the bar sank gradually, the deflection increasing more than 6 inches in ten minutes. The bar was finally broken by repeated bending, and showed that the crack above mentioned was produced by an imperfection in the casting, about one-fourth of the surface, or that portion in which the crack was observed, showing radiated lines of cooling and the remainder the close pasty appearance peculiar to tin ruptured by bending. The crack no doubt weakened the bar, as the final bending was resisted by but little more than three-fourths of the section.

Bar No. 30 (all copper).—This bar was made subsequently to the tests above described, and proved to be a much better bar than No. 1. It was cast in a cold iron mold, and poured when at a dazzling white heat. The surface was quite free from blow-holes, and in all respects the bar appeared to be sound. It is therefore taken as the standard bar of copper in this series of experiments. It was tested in a special transverse testing-machine, which will be described in connection with the account of the second series of copper-tin alloys, which latter were all tested with it. A remarkable difference was observed in softness and ductility between this bar and bar No. 1, the latter breaking at 650 pounds after a deflection of 0.707 inch, while the former had a deflection of 1.37 inches at 600 pounds, 3.49 inches at 800 pounds, and sustained finally a deflection of about 8 inches before breaking. This softness was indicated at the beginning of the test by the low limit of elasticity, which was 120 pounds, while in bar No. 1 it was at 225 pounds. A set of 0.01 inch took place in bar No. 1 at 250 pounds, but in bar No. 30 at less than 200 pounds. The breaking load of this bar is taken at 800 pounds, since this load produced a deflection of 3.49 inches. The fracture (Fig. 4) showed a homogeneous and compact metal, entirely free from blow-holes, with fine but very distinctly defined lines of cooling, perpendicular to each edge.

FIG. 4.

APPEARANCE OF THE FRACTURES.

After completing the tests by transverse stress, pieces were cut from each bar showing the transverse fracture. These pieces were examined by Prof. A. R. Leeds of the Stevens Institute of Technology, who made the following report concerning their colors and structures.

DESCRIPTION OF THE SURFACES OF FRACTURE OF A SERIES OF ALLOYS OF COPPER AND TIN BROKEN BY TRANSVERSE STRESS,—BY PROF. ALBERT R. LEEDS.

No. 1 (all copper).—Color, copper-red, altering by exposure to air into purple by film of suboxide, and into black by film of oxide of copper.

Surface in part large vesicular, in part curvilinear fibrous. Maximum diameter of vesicles, 7 mm.; maximum breadth of fibers, 1.5 mm.; length, 8 mm.

No. 2 (97.89 copper, 1.90 tin).—Color, red, slightly oxidized by exposure. Large and coarse vesicular; maximum diameter of vesicles, 5 mm.

No. 3 (96.06 copper, 3.76 tin).—Color, bright reddish-yellow, with faint traces of black oxide from exposure. Surface, small and finely vesicular.

No. 4 (92.11 copper, 7.80 tin).—Color, dull reddish-yellow. Homogeneous. Surface, finely aborescent.

No. 5 (90.27 copper, 9.58 tin).—Color, reddish-yellow, with spots of dark red and bright yellow. Surface, not homogeneous, in part vesicular, in part finely fibrous.

No. 6 (87.15 copper, 12.73 tin).—Color, brass-yellow in part, in part bluish white. Surface, not homogeneous, finely vesicular. Fracture, hackly.

No. 7 (80.95 copper, 18.84 tin).—Color, reddish-gray, with brass-yellow spots. Surface, reticulated fibrous.

No. 8 (76.64 copper, 23.24 tin).—Color, reddish-gray. Surface, faintly vesicular; interior of vesicles brass-yellow. Fracture, irregularly curved. Luster, dull.

No. 9 (69.84 copper, 29.89 tin).—Color, grayish-white. Surface, crystallization prismatic, diverging from center. Fracture, of large curvature. Luster, glistening.

No. 10 (68.58 copper, 31.26 tin).—Color, grayish-white, more white than the preceding. Surface, crystalline prismatic, diverging from the center. Fracture, of large curvature. Luster, glistening.

No. 11 (65.34 copper, 34.47 tin).—Color, bluish-gray, showing yellowish spots in some lights. Surface, interruptedly crystalline. Fracture, coarsely rounded. Luster, splendent.

No. 12 (62.31 copper, 37.35 tin).—Color, dark bluish-gray. Surface, laminated. Fracture, coarse hackly. Luster, splendent.

No. 13 (56.70 copper, 43.17 tin).—Color, bluish-white. Surface, crystallization eminent; crystals prismatic and diverging from center. Luster, splendent.

No. 14 (51.62 copper, 48.09 tin).—Color, bluish-white. Surface, crystallized, but not readily apparent. Fracture, coarse angular. Luster, splendent.

No. 15 (47.61 copper, 52.14 tin).—Color, grayish-white. Surface, finely granular. Fracture, waved. Luster, glistening.

No. 16 (44.52 copper, 55.28 tin).—Color, grayish-white. Surface, laminated granular. Fracture, coarsely waved. Luster, glistening.

No. 17 (42.38 copper, 57.30 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, uneven. Luster, glistening.

No. 18 (38.37 copper, 61.32 tin).—Color, grayish-white. Surface, crystallized, but not readily apparent. Fracture, coarse hackly. Luster, bright.

No. 19 (34.22 copper, 65.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic, and diverging from center. Prismatic angle, 130°. Sides of prism doubly striated, one set of striæ parallel to edge of prism, the other at an angle of 47° with the former. Luster, splendent.

No. 20 (25.85 copper, 73.80 tin).—Color, grayish-white. Surface, crystallization eminent, prismatic. Luster, splendent.

No. 21 (23.35 copper, 76.29 tin).—Color, grayish-white. Surface, crystallized, but not readily apparent. Fracture, hackly. Luster, bright.

No. 22 (20.25 copper, 79.63 tin).—Color, grayish-white. Surface, crystallization not large but eminent; prismatic diverging from center. Prismatic angle, 107°. Luster, splendent.

No. 23 (15.08 copper, 84.62 tin).—Color, grayish-white. Surface, crystallization, coarse with prismatic faces, divergent. Fracture, jagged. Luster, splendent.

No. 24 (11.49 copper, 88.47 tin).—Color, grayish-white. Surface, crystallization finely reticulated. Fracture, hackly. Luster, dull with bright reflections from scattered crystalline faces. Section, distorted.

No. 25 (8.57 copper, 91.39 tin).—Color, grayish-white. Surface, granular. Luster, dull, with glistening points. Section, distorted with curved edges.

No. 26 (3.72 copper, 96.31 tin).—Color, grayish-white. Surface, rounded granular. Luster, dull.

No. 27 (0.74 copper, 99.02 tin).—Color, grayish-white. Surface, crystallization feeble with undefined prismatic faces. Luster, bright.

No. 28 (0.32 copper, 99.46 tin).—Color, grayish-white. Surface, irregularly waved. Luster, dull.

No. 29 (All tin).—Color, bluish or grayish-white. Surface, slightly vesicular at center, prismatic at edges. Section, much distorted. Luster, bright.

TESTS BY TENSILE STRESS.

The bars broken by transverse stress were afterward tested by tension, two tension pieces being made from each bar, one from the upper and one from the lower end.

Each bar was marked with the letters A, B, C, D in addition to its number for the purpose of distinguishing different portions of the bar. The upper end of the bar was marked A, the lower end B, and the middle C and D, respectively, above and below the transverse fracture. The pieces tested by tension are distinguished in the records which follow, by the same number which was borne by the bar from which they were made and by the letters A or B, as the piece was taken from the upper or lower end of the bar.

The pieces to be tested were made of the shape and size indicated in the diagram below, whenever the sizes of the pieces from which they were cut were sufficient to allow it.

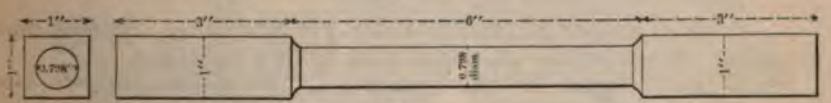

FIG. 5.

When the broken bar from which the test-piece was made was not long enough to make the piece of the size shown above, the cylindrical portion was shortened, leaving the square ends at least 3 inches in length. The cylindrical portion was turned with great care to a diameter of 0.798 inch, thus giving a sectional area of one-half square inch.

The pieces numbered No. 1 to No. 8 (all copper to 76.64 copper, 23.24 tin), inclusive, were turned in the lathe without difficulty, a gradually increasing hardness being noticed, the last named giving a very short chip, and required frequent sharpening of the tool. The turned surface of all these bars was made perfectly smooth by the turning tool. The color of the turned surface varied from copper-red to light golden-yellow, the color gradually becoming lighter with the increase of percentage of tin. In turning these bars, blow-holes of various sizes were

found in nearly all of them, No. 4 and No. 7 only being quite free from them; No. 1 and No. 2 had a very large number of all sizes, and Nos. 3, 5, 6, and 8 had each a few, usually of small size.

With the most brittle alloys it was found impossible to turn the test-pieces in the lathe to a smooth surface. No. 9 to No. 11 (29.89 to 34.47 tin) could not be cut with a tool at all. Chips would fly off in advance of the tool and beneath it, leaving a rough surface, or the tool would sometimes apparently crush off portions of the metal, grinding it to powder. These bars were not turned down to the standard size, 0.798 inch, but had the corners merely taken off, making the cylindrical portion nearly 1 inch diameter and 1 inch long.

No. 12 B (36.96 tin) gave even more trouble than No. 9 to No. 11. The piece broke in the lathe before the corners were taken off. No. 12 A was left for test without being turned.

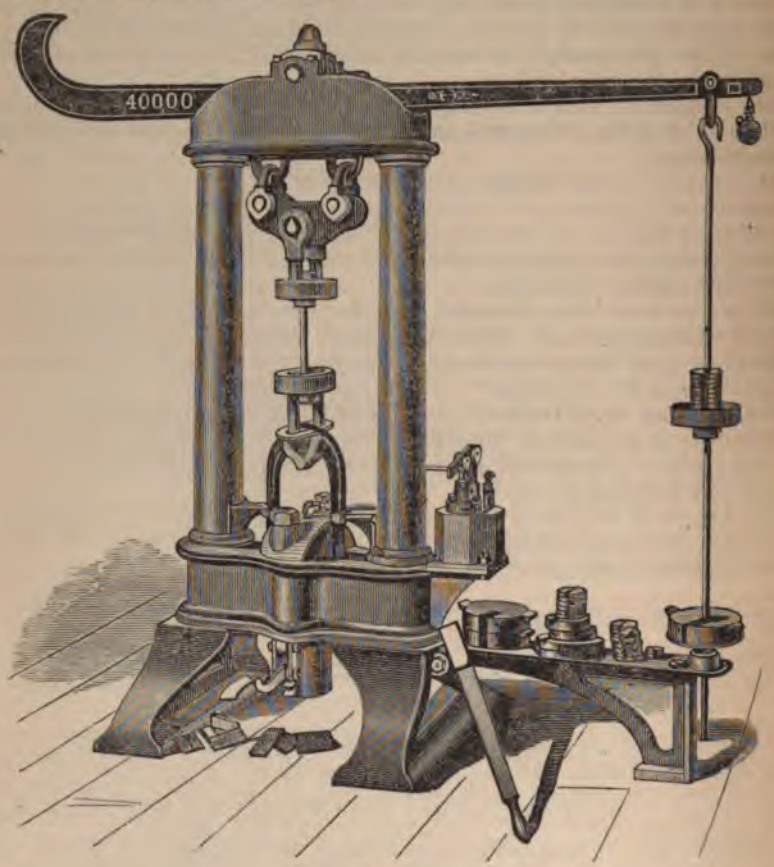

FIG. 6.

No. 13 and No. 14 (43.17 and 48.09 tin) worked like No. 9 to No. 11. No. 14 B (38.41 copper, 61.04 tin) proved to be much softer and more easily turned than No. 14 A (62.27 copper, 37.58 tin), and was turned to the standard diameter. No. 14 A was as hard as No. 12. This was due to the difference in composition of the two ends of this bar, as before described, the larger proportion of tin being at the bottom.

o. 15 was much softer than No. 13, but not so soft as No. 14 B. It , however, very weak, and broke in the lathe before being finished. 15 A was left without being turned.

o. 16 worked like No. 15, the tool taking off very fine chips and der.

o. 17 was a little softer, chips from the tool being easily reduced to der by being rubbed between the fingers. No. 17 A (45.93 copper, 0 tin) was somewhat harder than No. 17 B (38.83 copper, 60.79 tin), ch was due, as in the case of No. 14, to liquation.

o. 18 to No. 20 worked like No. 17 B, the chips being very weak and tle.

o. 21 was not turned, on account of the cavity which extended through ength.

o. 22 to No. 29 all worked very easily in the lathe, showing increas- softness as the proportion of tin increased.

he apparatus used in the tests by tensile stress was the testing ma- ıe in the Mechanical Laboratory of the Stevens Institute of Tech- ›gy, a cut of which is shown on preceding page.

he elongations were measured by means of a pair of finely-pointed ders, with a fine screw-attachment, taking the distances between two ıts marked on the cylindrical portion of the test-piece, about 5 inches rt. The distances taken by the dividers were then measured on a ıdard scale, divided to hundredths of an inch. In this way the smallest ıgation which could be observed was 0.01 inch, which was probably ıany cases beyond the elastic limit, so that from these experiments ther the elastic limit nor the modulus of elasticity within that limit ld be accurately determined. As a close approximation, however, elastic limit is taken from the curves of elongations, the point at ch the curves appear to change their direction toward the horizontal ıg considered to indicate the limit.

ables giving the record of the test of each bar are appended. The ›wing is a summary of the results:

TABLE III.—FIRST SERIES—COPPER AND TIN ALLOYS.

Tests by Tensile Stress.

No.	Composition by analysis.		Diameter.		Total elongation—parts of original length.	Tenacity per square inch.		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds.*		
1 A	Cast copper		0.798	0.790	0.0060	14,180	14,464	12,000	
1 B	....do	.....	0.798	0.742	0.0033	11,340	11,509	10,000	
Mean	.....	.....	.....	0.766	0.0047	12,760	12,987	11,000	
2 A	97.95	1.88	0.798	0.730	0.1566	25,200	30,104	10,000	
2 B	97.83	1.92	0.798	0.717	0.1100	24,960	29,142	10,000	
Mean	97.89	1.90	.....	0.724	0.1333	24,580	29,623	10,000	
3 A	96.16	3.71	0.798	0.696	0.1317	30,960	40,687	16,000	
3 B	95.96	3.80	0.798	0.668	0.1540	33,040	44,696	16,000	
Mean	96.06	3.76	.....	0.691	0.1429	32,000	42,692	16,000	
4 A	92.14	7.84	0.798	0.730	0.0780	29,300	35,002	20,000	
4 B	92.07	7.76	0.798	0.737	0.0325	27,780	32,559	18,000	
Mean	92.11	7.80	.....	0.734	0.0553	28,540	33,780	19,000	
5 A	90.11	9.66	0.798	0.745	0.0412	26,720	30,649	15,000	
5 B	90.43	9.50	0.798	0.760	0.0319	27,000	29,761	16,500	
Mean	90.27	9.58	.....	0.753	0.0366	26,860	30,205	15,750	
6 A	87.15	12.69	0.798	0.792	0.0185	26,700	27,098	20,000	
6 B	87.15	12.77	0.798	0.773	0.0480	32,160	34,263	20,000	
Mean	87.15	12.73	.....	0.783	0.0333	29,430	30,680	20,000	
7 A	80.99	18.92	0.798	0.798	0.004	33,600	33,600	.....	
7 B	80.90	18.75	0.798	0.798	0.004	32,360	32,360	.....	
Mean	80.95	18.84	.....	0.798	0.004	32,980	32,980	.....	
8 A	76.67	23.24	0.798	0.798	0	20,600	20,600	20,600	
8 B	76.60	23.23	0.798	0.798	0	24,420	23,420	23,420	
Mean	76.64	23.24	.....	0.798	.....	22,010	22,010	22,010	
9 A	69.90	29.85	0.985	0.985	0	7,006	7,006	7,006	
9 B	69.77	29.92	0.972	0.972	0	4,164	4,164	4,164	
Mean	69.84	29.89	.....	0.979	.....	5,585	5,585	5,585	
10 B	68.57	31.30	.....	.....	0	1,620	1,620	1,620	Rectangular sec 0.994″ × 1.005′
11 A	65.31	34.47	0.974	0.974	0	2,376	2,376	2,376	
11 B	65.36	34.47	0.975	0.975	0	2,025	2,025	2,025	
Mean	65.34	34.47	.....	.....	.....	2,201	2,201	2,201	
12 A	61.83	37.74	.....	.....	0	250	250	250	
12 C	62.79	36.96	.....	.....	0	1,125	1,125	1,125	
Mean	62.31	37.35	.....	.....	.....	688	688	688	
13 A	56.58	43.11	.....	.....	0	1,259	1,259	1,259	Rectangular sec 0.998″ × 1.004′
13 B	56.82	43.22	0.975	0.975	0	1,650	1,650	1,650	
Mean	56.70	43.17	.....	.....	.....	1,455	1,455	1,455	
14 A	62.27	37.58	0.968	0.968	0	1,170	1,170	1,170	
14 B	38.41	61.01	0.798	0.798	0	3,940	3,940	3,940	
Mean	51.62	48.09	.....	.....	.....	2,555	2,555	2,555	
15 A	47.72	51.99	1.055	square.	0	950	950	950	
15 C	"	"	"	"	0	2,100	2,100	2,100	
Mean	47.61	52.14	.....	.....	.....	1,525	1,525	1,525	
16 A	44.62	55.15	0.980	0.980	0	3,460	3,460	3,460	
16 B	44.42	55.41	0.798	0.748	0	2,560	2,560	2,560	
Mean	44.52	55.28	.....	.....	.....	3,010	3,010	3,010	
17 A	45.93	53.80	0.798	0.748	0	2,260	2,260	2,260	
17 B	38.83	60.79	0.798	0.748	0	5,560	5,560	5,560	
Mean	42.38	57.30	.....	.....	.....	3,910	3,910	3,910	
18 A	38.37	61.32	0.798	0.748	0	.....	.....	.....	Broke before tes
18 B	38.37	61.32	0.798	0.748	0	2,820	2,820	2,820	

Tests by Tensile Stress—Continued.

Composition by analysis.		Diameter.		Total elongation—parts of original length.	Tenacity per square inch.		Elastic limit—pounds per square inch.	Remarks.
Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
		Inches.	*Inches.*		*Pounds.*	*Pounds.*		
34.22	65.80	0.798	0.748	0	.....	.....	.....	Broke before test.
34.22	65.80	0.799	0.799	0	3,371	3,371	3,371	
26.57	73.08	0.799	0.799	0	1,795	1,795	1,795	
25.12	74.51	0.798	0.798	0	1,500	1,500	1,500	
25.85	73.80	.....	.....	.....	1,648	1,648	1,648	
22.80	76.89	0.997	0.997	0.0017	6,275	6,275	6,275	Rectangular section 0.997″ × 1.007″.
23.89	75.68	1.000	1.000	0	7,275	7,275	7,275	Rectangular section 1″ × 1.02″.
23.35	76.29	.....	.....	.....	6,775	6,775	6,775	
20.28	79.63	0.798	0.798	0	6,440	6,440	6,440	
20.21	79.62	0.799	0.799	0	2,234	2,234	2,234	
20.25	79.63	.....	.....	.....	4,337	4,337	4,337	
15.12	84.58	0.798	0.798	0	550	550	550	Result doubtful.
15.04	84.65	0.798	0.798	0.0067	6,520	6,520	5,500	
15.08	84.62	.....	.....	0.0067	6,520	.....	.....	
11.49	88.44	0.798	0.768	0.0740	6,600	7,050	3,000	
11.48	88.50	0.798	0.795	0.008	6,160	6,204	4,000	
11.49	88.47	.....	0.782	0.0410	6,380	6,627	3,500	
8.82	91.12	0.798	0.730	0.0714	6,000	7,167	3,500	
8.32	91.66	0.798	0.740	0.0660	6,900	8,021	3,500	
8.57	91.39	.....	0.735	0.0687	6,450	7,534	3,500	
3.70	96.30	0.798	0.680	0.0983	4,300	5,920	2,500	
3.74	96.32	0.798	0.660	0.148	5,260	7,687	3,000	
3.72	96.31	.....	0.670	0.1232	4,780	6,804	2,750	
0.75	98.98	0.798	0.550	0.316	3,600	7,576	.....	
0.72	99.06	0.798	0.540	0.1397	3,700	8,157	.....	
0.74	99.02	.....	0.545	0.2279	3,650	7,867	.....	
0.32	99.46	0.798	0.455	0.3600	4,700	14,453	2,500	Tenacity of fractured section doubtful.
0.32	99.45	0.798	0.475	0.3448	4,250	11,992	2,500	Do.
0.32	99.46	.....	0.465	0.3544	4,475	13,223	2,500	
Cast	tin....	0.798	0.490	0.2833	2,800	.....	.....	
"	"	0.798	0.300	0.4269	4,200	.....	.....	Do.
.....	.....	.....	0.395	0.3551	3,505	.....	.....	
Cast	copper	0.798	0.725	0.0752	29,200	34,790	14,000	
"	"	0.798	0.740	0.0541	26,400	30,201	14,000	
.....	.....	.....	0.733	0.0647	27,800	32,496	14,000	

TESTS BY TENSILE STRESS.

he results of the tests by tensile stress agreed in general very closely
those by transverse stress, the relative strength and ductility of the
ous bars being the same under either kind of test. This is very
nly shown by an inspection of the curves in Plate VIII, in which
transverse and tensile strengths and the ductility are compared.
ar No. 1 (all copper) proved deficient in both strength and ductility,
nsequence of the presence of a large number of blow-holes. The
should be kept in mind throughout this discussion of results that
e cast pieces were purposely used, although frequently unsound, as
as intended to ascertain the value of each alloy as cast. It will sub-

sequently be determined how far the occurrence of unsoundness in casting can be avoided by special treatment, and how the tenacity and other valuable properties may be thus improved. No. 1 A had a tenacity of 14,180 pounds per square inch, and No. 1 B, 11,340 pounds, with total elongations of only 0.03 and 0. 02 inch respectively. The contrast between the properties of No. 1 and No. 30 is as plainly shown in the tensile as in the transverse tests, the latter having a tenacity of 29,200 and 26,400 pounds in the A and B ends respectively, with elongations of 0.376 inch and 0.271 inch. The tensile strength of No. 30 A is unusually high for cast copper.

Bar No. 2 (97.89 copper, 1.90 tin) was very much more ductile than No. 1, but was rendered deficient in strength by blow-holes.

Bar No. 3 (96.06 copper, 3.76 tin) was stronger and more ductile than No. 2. The fractures of No. 3 A and No. 3 B both showed blow-holes, which probably decreased their strength.

Bars No. 4 and No. 5 (7.80 and 9.58 tin) showed an exception to the rule of increase of strength with increase in the proportion of tin, and were both weaker under tensile stress than No. 3, while in the transverse tests No. 3 was the weakest and No. 5 the strongest of the three bars. The reason of this weakness does not appear to be the presence of blow-holes, as No. 3 had more of these than either No. 4 or No. 5. In the case of No. 5 the weakness is probably due to the want of homogeneity of the metal. As observed in the notes on transverse tests, the fracture by transverse stress was not homogeneous, the central portion being dark red or brownish-red, while the outer portions were of a reddish-yellow to yellowish-gray color.

In the fractures under tensile tests these same contrasts of color were also observed, varying slightly from those of the transverse fracture. The yellowish-colored metal being partly cut away in turning the cylindrical test-piece, the section left was composed of a larger proportion of the dark-colored metal, which was probably weaker than the other. The dark color appeared as if it might have been due to oxidation of the copper, rather than to the formation of a distinct alloy of the pure metals, as no alloy of the whole series in any way resembled the central portion of bar No. 5 in color.

The more rapid cooling of the metal at the surface than in the center may have made the exterior portions the stronger, and these having been cut away by turning the tension pieces, this may account for the weakness of the latter.

Bar No. 6 (87.15 copper, 12.73 tin) showed a marked difference in tenacity in the upper and lower parts of the bar, No. 6 A (87.15 copper, 12.96 tin) breaking at 26,700 pounds per square inch, and No. 6 B (87.15 copper, 12.77 tin) at 32,160 pounds. A small blow-hole appeared in the fracture of No. 6 A, but it was not large enough to account for the difference in strength. The cause is more probably the difference of structure of the metal in the two ends of the bar. The fracture of No. 6 A was like the transverse fracture in appearance, coarse, granular, and mottled in color. No. 6 B was also mottled, but much more finely, a close observation only revealing the two distinct colors of the metal. The structure was also much more compact. The analysis of the turnings from each of these pieces shows the composition to be almost precisely the same. The difference in structure may have been caused by the difference in pressure at the top and bottom of the mold.

Bar No. 7 (80.95 copper, 18.84 tin) was the strongest of the series, the results of the tensile tests agreeing with those of the transverse tests. The tension-pieces showed but little ductility, both breaking after an

elongation of only 0.02 inch. No. 7 A (80.99 copper, 18.92 tin) showed a lack of homogeneity in color, and was somewhat weaker than No. 7 B (80.90 copper, 18.75 tin).

Bar No. 8 (76.64 copper, 23.24 tin) was much weaker than No. 7, and had so little ductility that no elongation amounting to 0.01 inch could be detected. The fractures were similar to the transverse fracture, with several very small blow-holes. Bars No. 8 to No. 20 (23.24 to 73.80 tin), inclusive, had all such exceedingly slight ductility that none of them elongated 0.01 inch tensile stress. Their comparative ductility, therefore, cannot be determined from these tests. The fact of their having such a small degree of ductility, moreover, unfits them for any use in which strength is required, and their comparative ductility is of no practical value.

Bars No. 9 and No. 10 (29.89 and 31.26 tin) were so hard that great difficulty was experienced in holding them in the grip-blocks of the tensile machine. These grip-blocks were made of very hard cast steel, and the gripping-edges were scored like a file. Instead of cutting into the metal of No. 9 and No. 10, as they did with all metals softer than hardened steel, they ground off the surface and let the pieces slip out.

No. 9 A was turned in the middle portion to the cylinder form, and was 1 inch long and 0.985 inch in diameter. It broke, however, in the square end of the specimen, about 1 inch from the end of the turned portion, thus fracturing a section which was one-third larger than the minimum section of the piece. This phenomenon took place also in bar No. 13 (56.70 copper, 43.17 tin), and may indicate planes of weakness in portions of the test-piece or the existence of internal strains greater in some portions of the pieces under test than in others.

All of the brittle pieces showed not only general weakness but irregularity of strength. The upper and lower portions of the bar often gave very different results, and differed so irregularly that they seemed to follow no law whatever. The tensile strength of pieces of which the chemical analyses showed similar constitution, as well as the appearance of the metal, often gave widely-varying results.

Bars No. 11 to No. 20 (34.47 to 73.80 tin) all exhibited similar deficiency of strength. The peculiarities of each are given in the notes in the appended tables under the record of the test of each bar. The minimum average strength was shown by bars No. 12 and No. 13 (37.35 and 43.17 tin), corresponding to the results of the transverse tests. From No. 13 to No. 21 there was a somewhat irregular increase of strength, No. 21 giving a second maximum point of strength in the series as occurred with the transverse tests.

Bar No. 21 (23.35 copper, 76.29 tin) was tested at its original square section, on account of the existence of a cavity through its center, before described. No. 21 A showed some indications of ductility, an elongation of 0.01 inch being observed.

Bar No. 22 (20.25 copper, 79.63 tin) showed no elongation amounting to 0.01 inch. No. 22 A (20.28 copper, 79.63 tin) was nearly three times as ductile as No. 22 B (20.21 copper, 79.62 tin).

Bars No. 23 to No. 29 (84.62 to all tin) showed regularly increasing ductility, No. 23 B breaking after an elongation of 0.02 inch and No. 29 B after an elongation of 2.58 inches.

Bar No. 23 A gradually elongated under the load of 3,300 pounds for two minutes before breaking, the elongation increasing from 0.13 to 0.37 inch. This "time-test" showed the same result as those given in the tests by transverse stress, viz, that the ductile metals may show a

greater or a less resistance to stress as the load is applied for a shorter or longer time.*

The ductile bars showed a much greater uniformity of strength in the upper and lower portions of the bars than the brittle pieces, when the time occupied by the test was the same.

"Time-tests" of shorter duration were made with nearly all the bars from No. 23 to No. 29, with the uniform result of increasing the elongation. With No. 29 A a special "time-test" was made to determine the difference in resistance to slow and rapid rupture. This bar being composed entirely of tin, and apparently a good casting, it would be expected that tests of the two pieces, one from the upper and one from the lower end of the bar, would show little, if any, difference in strength. No. 29 A was first tested with a load of 1,700 pounds, which caused an elongation of 0.15 inch. This load was then reduced to 1,250 pounds, and the reading again taken, showing an elongation of 0.19 inch, which increased in two minutes to 0.27 inch. The load was then increased to 1,400 pounds, and the elongation was 0.32 inch. The load was allowed to remain on the bar for ten minutes, and the elongation gradually increased to 1.70 inches, when the bar broke. It seems probable from this test that the load of 1,400 pounds would have broken the piece even if the load of 1,700 pounds had not been placed on it at the beginning of the test.

Bar No. 29 B was then tested in a different manner. The load was gradually but rapidly increased to 2,100 pounds, without stopping longer than a sufficient time to take the reading of the elongations at 975, 1,180, 1,290, 1,600, and 2,000 pounds. At 2,100 pounds the elongation was read, 1.88 inches. The piece then extended very rapidly, and at the same time its resistance, as measured by the scale-beam, reduced to 1,700 pounds. The pump of the hydraulic press was run as fast as possible, but the beam could not be balanced by so doing beyond 1,700 pounds. The piece sustained this load a few seconds, and then broke after an elongation of 2.58 inches.

Comparing these two tests, it is seen that the resistance of No. 29 A to an elongation greater than 0.19 inch was never greater than 1,400 pounds, while that of No. 29 B was 2,100 pounds, or 50 per cent. more than the former; which 50 per cent. apparent increase of strength may have been entirely due to the greater rapidity of the test of No. 29 B and not to its inherent strength. The fact that the difference in strength is only apparent is confirmed by the experiments by torsional stress on pieces from the same bar, which are hereafter described. These showed that torsion-pieces No. 29 A and No. 29 B, one from the top the other from the bottom of the bar, each tested by a moderately slow motion, each gave a resistance of 142 foot-pounds torsional moment; piece No. 29 C, from the middle of the bar, tested in the same manner resisted 13.2 foot-pounds, while No. 29 D, a piece also taken from the middle of the bar and originally adjoining No. 29 C, tested by very slow motion and left under stress for many hours, resisted only 9.2 foot-pounds or about 30 per cent. less than either of the other pieces.

The strength per square inch of fractured section is given in the tables for the purpose of comparison, but it is not an indicator of either the ultimate or the useful strength of the metals, except in those which have but a limited degree of ductility and which do not show increase of elongation under continued stress. In the cases of ductile metals, the portion of the test-piece just above and below the point of fracture gradually narrowed down as the breaking load was reached, and in most cases this narrowing or "necking down" was very rapid the instant be-

* See paper by the writer in appendix on The Effects of Time, &c.

fore fracture. In such cases the beam of the scale often dropped a few seconds before fracture took place, showing a decrease of resistance and consequently a decrease of stress. The final rupture was caused, therefore, by some load less than the maximum load which the piece sustained before the rapid necking down commenced. In a few cases it was possible to follow the decrease of resistance to stress by balancing the scale-beam, nearly to the instant of rupture, but never entirely to it, so that the actual load sustained by the piece at the instant of rupture could not be determined. The so-called "tenacity per square inch of fractured section," found by dividing the maximum load sustained by the piece by the area of section measured after fracture, is therefore no indication of the strength of the metal. Even in the cases in which the decrease of stress was not observed, and the scale-beam dropped apparently at the same instant that rupture took place, it is not always certain that decrease of resistance does not take place first, although only a fraction of a second before rupture, nor, therefore, that the final section (measured after rupture) even sustained the load indicated by the scale-beam.

The following description of the fractures by tensile stress has been made by Prof. A. R. Leeds.

DESCRIPTION OF THE SURFACES OF FRACTURE OF A SERIES OF ALLOYS OF COPPER AND TIN BROKEN BY TENSILE STRESS.

BY PROF. ALBERT R. LEEDS.

No. 1 B (all copper).—Color, copper-red, with a purple film of suboxide; surface, in part large vesicular, in part crystalline, radiating toward edge.

No. 2 A (97.95 copper, 1.88 tin).—Color, copper-red; surface deeply vesicular; fracture, uneven; luster, dull, with bright points.

Bar No. 2 B (97.83 copper, 1.92 tin).—Color, copper-red, inclining toward yellow; surface, finely vesicular; fracture, uneven; luster, dull, with fine bright points.

Bar No. 3 B (95.96 copper, 3.80 tin).—Color, reddish-yellow; surface, finely vesicular, the curved surfaces interrupting; luster, dull.

Bar No. 4 B (92.07 copper, 7.76 tin).—Color, yellowish-red in part, in part reddish-yellow; surface, vesicular; luster, dull.

Bar No. 5 A (90.11 copper, 9.66 tin).—Color, yellowish-red; surface, crystallization, fibrous, radiate, finely vesicular on faces; luster, dull.

Bar No. 5 B (90.43 copper, 9.50 tin).—Color, grayish-yellow; surface, coarse vesicular; fracture, jagged; luster, dull.

Bar No. 6 A (87.15 copper, 12.69 tin).—Color, bluish-white with bright yellow spots; surface, confusedly vesicular; fracture, hackly; luster, dull.

Bar No. 6 B (87.15 copper, 12.77 tin).—Color, reddish-yellow, with bluish-gray points, producing a general impression of orange; surface, broadly crystalline, with surfaces of prismatic faces finely vesicular; luster, dull, with minute bright points.

Bar No. 7 A (80.99 copper, 18.92 tin).—Color, grayish-white with yellow points; surface, not apparently crystalline; fracture, coarse hackly; luster, dull.

Bar No. 8 B (76.60 copper, 23.23 tin).—Color, yellowish-gray; surface, vesicular, with smooth intervening faces; fracture, even; luster, shining.

Bar No. 9 A (69.90 copper, 29.85 tin).—Color, yellowish-gray to bluish-gray in different lights; surface, broadly-bladed prismatic, and diverging from center; fracture, smooth; luster, splendent.

Bar No. 10 A (68.58 copper, 31.26 tin).—Color, yellow to bluish-gray;

surface, broadly-bladed prismatic and diverging from center; fracture, smooth; luster splendent.

Bar No. 11 A (65.31 copper, 34.47 tin).—Color, yellow to bluish-gray; surface, crystallized, but not readily apparent; fracture, coarsely waved; luster, splendent.

Bar No. 12 B (62.79 copper, 36.96 tin).—Color, blue; surface, coarsely waved and pitted; luster, splendent.

Bar No. 13 A (56.58 copper, 43.11 tin).—Color, bluish; surface, crystallization eminent, prismatic blades diverging from center; fracture, uneven; luster, splendent.

Bar No. 14 A (62.27 copper, 37.58 tin).—Color, bluish-gray in part, in part reddish-gray; surface, crystallized but not readily apparent; fracture, uneven; luster, dull.

Bar No. 14 B (38.41 copper, 61.04 tin).—Color, bluish-gray; surface, crystallized but not readily apparent; fracture, coarsely waved; luster, splendent.

Bar No. 15 B (47.49 copper, 52.29 tin).—Color, bluish-gray to grayish-white; surface, waved; fracture, irregular; luster, glistening.

Bar No. 16 B (44.42 copper, 55.41 tin).—Color, grayish-white; surface, crystallized but not readily apparent, waved and feebly vesicular; luster, glistening.

Bar No. 17 B (38.83 copper, 60.79 tin).—Color, grayish-white; surface, finely waved vesicular; luster, shining, with bright points.

Bar No. 18 A (43.37 copper, 56.37 tin).—Color, grayish-white; surface, crystallization prismatic, with waved lines on prismatic faces; luster, splendent.

Bar No. 18 B (43.36 copper, 56.40 tin).—Color, grayish-white; surface, crystallized but not readily apparent, feebly vesicular; fracture, irregular; luster, glistening, bright lines of reflection from crystalline faces.

Bar No. 19 A (40.32 copper, 59.46 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; the prismatic faces large and striated; prismatic angle, 91°; luster, splendent.

Bar No. 19 B (40.24 copper, 59.44 tin).—Color, grayish-white; surface, crystallization eminent, prismatic; luster, splendent.

Bar No. 20 A (26.57 copper, 73.08 tin).—Color, grayish-white; surface; crystallization eminent, the faces in part prismatic, in part having an octahedral aspect; luster, splendent.

Bar No. 20 B (25.12 copper, 74.51 tin).—Color, grayish-white; surface, crystallized but not readily apparent, waved and feebly vesicular; fracture, rough; luster, glistening, with bright surfaces of reflection.

Bar No. 21 B (33.89 copper, 75.68 tin).—Color, grayish-white; surface, feebly crystalline and vesicular; fracture, hackly; luster, glistening, with bright points.

Bar No. 22 A (20.28 copper, 79.63 tin.)—Color, grayish-white; surface, crystallization eminent, prismatic faces irregular; luster, splendent.

Bar No. 22 B (20.21 copper, 79.62 tin).—Color, grayish-white; surface, confusedly crystalline, with prismatic faces; luster, splendent.

Bar No. 23 A (15.12 copper, 84.58 tin).—Color, grayish-white, in part with yellow tarnish; surface, crystallization eminent, broad prismatic faces, radiate; luster, splendent.

Bar No. 24 B (11.48 copper, 88.50 tin).—Color, grayish-white; surface, crystalized fibrous; fracture, hackly; luster, glistening, with bright lines of reflection from edges of crystals.

Bar No. 25 A (8.82 copper, 91.12 tin).—Color, grayish-white; surface, irregular and feebly vesicular; luster, dull.

Bar No. 26 B (3.74 copper, 96.32 tin).—Color, grayish-white; surface, fibrous, in part slightly vesicular; luster, dull.

Bar No. 27 A (0.75 copper, 98.98 tin).—Color, grayish-white; surface, brous; fracture, jagged; luster, dull.

PHOTOGRAPHS OF FRACTURES.

The surfaces of fracture by tensile and transverse stresses, which were ıbmitted to Professor Leeds for description, were also photographed by im. Copies of these photographs are presented with this report.

Considerable trouble was experienced and a great deal of time con-ımed in mounting the pieces so as to obtain the proper effect of light ıd shade necessary to show the peculiarities of structure of the frac-ıred surfaces. The best effect was finally obtained by magnifying the ıage of the fracture, so that the photographs were one and a half times ıe original size of the specimen. In general six pieces were taken at ıce, as it was found that if more than this number were taken, the dif-rence in structure, and consequently in reflection of light, was such ıat the treatment necessary to obtain good pictures of some of the ieces was not suitable for others.

In this way twenty-two plates were made, and these were afterward ombined into six groups of four plates each, and reduced to about half ze, or to about three-fourths of the size of the specimens. The six lates thus formed are those submitted herewith. They are numbered om No. 1 to No. 6, and the following is a key to the arrangement of ıe fractures which are photographed in each:

ey to the Arrangement of Photographs of Fractures of Copper-Tin Alloys.

Plate No. 1.

	1 A [Copper.]		28 B
7 C		2 D	27 B
5 B		3 D	29 C [Tin.]
21 B	21 B²	2 D	5 A
13 A	14 B	8 D	2 C
11 C	12 B	3 D	1 D [Copper.]

Plate No. 2.

18 C	15 B	8 D	6 B
18 D	16 B	7 B	6 A
17 A	17 D	7 A	5 A
20 C	19 B	5 A	2 D
20 B	19 C	4 D	2 C
22 A	22 B	3 D	1 D

Plate No. 3.

27 C	23 A		
28 B	22 B		
		Tin	15 A
29 B	1 D		
26 B	24 B		
		19 C	19
10 A	25 A		
9 A	23 A		

Plate No. 4.

3	3	29	
2	2	28	28
1	1	27	27
	14 A	26	26
14 B			
	15 A	25	25
12 B			
	12 A	24	24

Plate No. 5.

1	1	6	6
2	2	7	7
3	3	8	8
3	3	9	9
4	4	10	10
5	5	11	11

Plate No. 6.

21	21	17	17
22	22	16	16
23	23	15	15
18	18	12	12
19	19	13	13
20	20	14	14

Those numbers which have not the letters A, B, C, D annexed are ractures by transverse stress, those with letters affixed are tensile frac-ures, except the five pieces in the upper left-hand corner of Plate No. 1, hich were fractures by torsion, and No. 15 A and No. 19 C, in Plate No. 3, the former of which is a side view, showing surface markings of rystallization. The latter was an accidental fracture, which shows a highly crystalline structure.

TESTS BY TORSIONAL STRESS.

After breaking the pieces by tensile stress, as described above, the square ends of the fractured pieces were turned into pieces suitable for tests by torsion. The standard shape and size of these torsion pieces are shown in the sketch below:

FIG 7.

The pieces were turned with great care to a diameter of 0.625 inch, as measured by a standard gauge, and the distance between fillets and the shape of the fillets were made uniform by comparing with a standard templet. The pieces which were too brittle to be turned in a lathe were shaped by grinding with an emery-wheel in an apparatus designed for the purpose.

The pieces from each bar were marked with the letters A, B, C, D in addition to the number of the bar, these letters corresponding with those on the tension pieces, A being the piece nearest the top of the bar, B nearest the bottom, and C and D from the middle.

FIG. 8.

The tests by torsion were made in Prof. R. H. Thurston's machine for testing the strength, elasticity, shock-resisting power of resilience, and the homogeneousness of metal. The material is tested by twisting, by which is obtained a great range of distortion and the most favorable treatment for revealing all the characteristics of the test-piece. The latter is placed between two independent jaws, one of which is rotated by means of an arm in the simpler styles, and in the one here illustrated by a worm, L, and gear M. The force thus applied is transmitted through

the test-piece to the other jaw, from which depends a weighted arm or pendulum, B. The resistance offered by this pendulum to the force tending to deflect it from the vertical, causes that force to react upon the test-piece and produce distortion and fracture. The angular position assumed by the pendulum is a measure of that force. A pencil is secured to the pendulum and is moved when the latter is thrust forward, in a direction perpendicular to the plane of rotation, by its contact with a guide-curve, F, fastened to the frame of the machine. A cylinder, G, is secured to that jaw, which is moved by the gear-wheel. The cylinder and the pencil have precisely the relative movements of the two ends of the test-piece, so that the length of the curve, automatically described by the pencil upon a paper wrapped about the cylinder, becomes a measure of the degree of distortion or of the ductility, and its height measures the resistance offered by the material.

The material thus tells its own story, these elements recording themselves simultaneously and continuously from the initial point to the point of final rupture.

The diagrams made by the machine show to the eye at a glance the nature of the material tested and are very characteristic.

In making a test with this machine, the test-piece, of the form shown on previous page, is placed in the jaws of the two wrenches, each of which takes one of its squared ends, and force being applied to the handle L, the stress thrown upon the specimen is transmitted through it to the weighted arm B, causing it to swing about its axis until the weight exerts a moment of resistance which equilibrates the moment of the applied force. As the magnitude of the distorting force changes, the position of the weight simultaneously changes, and the pencil indicates, at each instant, the value of the stress upon the test-piece. As the piece yields under stresses of increasing amount, also, the pencil is carried in the direction of the circumference of the cylinder on which its record is made, and to a distance which is proportional to the amount of distortion, *i. e.* to the "total angle of torsion."

As the applied force increases, the specimen yields, and finally rupture occurring, the pencil returns to the base-line, at a distance from the starting-point which measures the angle through which the test-piece yielded before its fracture became complete.

Referring to the diagrams obtained in making these tests, which are appended to this report, it is seen that the vertical scale of the diagrams is a scale of torsional moments, and the horizontal scale is one of total angles of torsion. Since the resistance to shearing, in a homogeneous material, varies with the resistance to longitudinal stress, it follows that the vertical scale is also for such materials a scale of direct resistance, and that with approximately homogeneous substances this scale is approximately accurate where all specimens compared are of the same dimensions. Since the elasticity of the material is measured by the ratio of the distorting force to the degree of temporary distortion produced, the diagrams will exhibit the elastic properties of the material, as well as measure its ductility and its resilience.

It will be noticed also in these diagrams that the first portion of the line is usually a curve of small radius, convex toward the axis of abscissas, and that the line then rises at a slight inclination from the vertical, but becoming very nearly straight until, at a point some distance above the origin, it takes a reversed curvature. The first portion of the line is probably formed by the yielding of the packing-pieces securing the heads of the specimen, and, after they have taken a bearing, by the early yielding in some materials of particles already overstrained by

internal stresses. When a firm hold is obtained, the line becomes nearly straight, and the amount of the distortion is seen to be approximately proportional to the distorting force, and the inclination of the line is therefore a measure of the stiffness of the material.

The point of the line where the reversed curvature takes place marks the limit of elasticity, that is, the point at which the distortion increases suddenly much more rapidly than the applied force.

The brittle metals, in which these elastic limits are not reached before fracture, also do not give in the torsion diagram any curve with reversed curvature, but the lines rise nearly straight, with a slight inclination from the vertical till fracture takes place.

The following rules are of service in interpreting the diagrams:

(1) *To determine the homogeneousness of the material.*

Examine the form of the initial portion of the diagram between the starting-point and the first sudden change of direction which indicates the elastic limit. Notice also its inclination from the vertical and compare with it the inclination of the "elasticity line."

A perfectly straight line beneath the elastic-limit, perfectly parallel with the "elasticity line," shows the material to be *homogeneous as to strain; i. e.*, to be free from internal strains such as are produced by irregular and rapid cooling or by working too cold. Any variation from this line indicates the existence and measures the amount of strain. A line considerably curved exhibits the existence of such strain.

Next examine the form of the curve immediately after passing the elastic-limit.

A line rising from the elastic limit regularly and smoothly, approximately parabolic in form, and concave toward the base line, indicates *homogeneousness to structure* and the absence of such imperfections as are produced in wrought iron by cinder, or in cast metals which have been worked from ingots, by porosity of the ingot.

A line turning the corner sharply when passing the elastic limit and then running nearly or quite horizontal, as in irons usually and in low steel, or actually becoming convex toward the base-line, as with some of the woods, and then after a time resuming upward movement by taking its proper parabolic path, indicates a decided want of this kind of homogeneity. The relative length of the depressed portion of the line, and the amount of depression, measure the relative defectiveness of materials compared in this respect.

Finally compare the diagrams produced by several specimens of the same kind of material or from the same mass.

Homogeneousness in general character and *homogeneousness in composition* are proven by the precise similarity of these diagrams, while greater or less variation of the curves compared indicates a greater or less difference in the specimens of which they are autographs.

Materials should usually exhibit great homogeneousness in all these three ways to be perfectly reliable. Perfect homogeneousness is not to be expected in either respect.

(2) *To determine the elastic resistance of the specimen.*

Measure the height of the curve at the elastic limit, using the scale of torsion, or for tension, which is given for each machine and for each standard size of test-piece.

(3) *To determine the resistance offered to any given amount of extension or that producing a given set.*

Measure the height of the curve at the point whose distance from the origin measures the assumed degree of set.

(4) *To determine the ultimate resistance of the material.*

Measure in a similar manner the maximum height of the curve.

(5) *To determine the resilience of the piece within the elastic limit, i. e.,* the work required to produce an evident and permanent set, approximately proportional in amount to the degree of change of form of the specimen. (*This quantity measures the power of the material to resist shocks*, and its determination is evidently quite as important as that of resistance to simple stress, which latter forms one of the factors of the former.)

Measure the area comprised between the ordinate of the curve at the elastic-limit and the initial part of the curve. This quantity is proportional to the required value.

(6) *To determine the resilience of the material within any assumed limit of extension, i. e.,* the magnitude of blow required to produce a given set.

Measure the area of the curve up to the assumed limit.

(7) *To determine the total resilience* or shock-resisting power of the material.

Measure the total area of the diagram.

For ductile metals an approximate value is obtained by taking two-thirds the product of the maximum tenacity by the maximum extension. For hard and very brittle materials one-half the same product gives very accurately its values. For intermediate qualities the true value is more nearly two-thirds this product; also Swedish wrought iron, white cast iron and hardened steel, illustrate the first and the second classes; ordinary tool-steels are examples of the third class.

(8) *To determine the effect of a load given in pounds per square inch of stress.*

Find a point in the curve having an altitude which measures the given stress, the abscissa of that point measures the extension under that load. In other words, a point being found in the curve, the height of which above the base-line is equal to the load per square inch, its horizontal distance from the origin measures the extension of the material as produced by that stress.

In calculating the torsional moments from the diagrams the scale used was the following, the 100-pound weight being used on the arm:

$$\left.\begin{array}{l}\text{Foot-pounds of torsional moment}\end{array}\right\} = [(\text{inches of ordinate} \times 117.443) + 11.856].$$

For resilience the following scale was used:

$$\text{Resilience, in foot-pounds of work} = (\text{area of diagram in square inches} \times 20.496) + (\text{maximum abscissa in inches} \times 1.893).$$

These scales were determined by careful experiment and measurement on the machine used in the tests ("Standard" machine No. 7, Stevens Institute of Technology).

On comparing the autographic strain-diagrams of the torsion tests with the curves of tests by transverse and tensile stresses, made by plotting the figures of the records of the latter, Plate VIII, it will be seen that with each bar there is a very marked similarity in the shape of its curves produced by each of the three methods of test. The ductile materials, by either method of test, give curves which become nearly parallel to the axis of the abscissas long before fracture, while the brittle materials give curves in which the reversed curve, concave to the axis of abscissas, never takes place.

In testing the torsion pieces of all bars from No. 1 (all copper) to No. 7 (76.64 copper, 23.24 tin) inclusive, the weight on the end of the arm of the torsion machine was 100 pounds. In testing all the remaining metals the weight was either wholly removed and the weight of the arm

alone furnished the distorting and breaking force, or a weight of 30 pounds was substituted for the 100 pounds. In calculating the strength and the resilience from the diagrams, the ordinates of the curve are multiplied by a greater or less factor according as the greater or less weight was used on the arm. The ductility of the material is measured by the angle of torsion and is independent of the weight used.

In addition to the diagrams, tables are appended giving the results of the calculations made from them, viz, the area of the diagram, with the resilience calculated therefrom; the maximum ordinate, with its corresponding maximum torsional moment, which is approximately proportional to the tensile strength of the material; the ordinate at the elastic limit, with its corresponding torsional moment, which is also approximately proportional to the tensile strength at the elastic limit; and the angle of torsion, and the extension in parts of its original length of an exterior fiber or line of particles on the surface of the cylindrical portion of the test-piece, which is calculated from the angle of torsion and is directly proportional to the ductility.

From the appended tables, in which are given the results of the calculations of the autographic diagram of each test-piece, a condensed table has been made, which is given below, which gives the *average* of results of the several test-pieces from each bar. In making the averages, those tests which are evidently unsatisfactory, from the presence of large blow-holes in the center of the test-specimen, are rejected. In the tables at the end of the report the tests which are rejected are indicated.

TABLE IV.—TESTS BY TORSIONAL STRESS—AVERAGES OF RESULTS CALCULATED FROM THE AUTOGRAPHIC STRAIN-DIAGRAMS.

First series.—Copper and Tin Alloys.

Number.	Mean composition by analysis.		Area of diagrams.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility extension of exterior fiber.	Resilience.	Number of pieces averaged.	Remarks.
	Copper.	Tin.			Maximum.	At elastic limit.	Maximum.	At elastic limit.				
			Sq. in	*Degrees.*	*Inch.*	*Inch.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*		
1	Copper.		1.30	40.5	0.47	0.19	65.66	33.17	0.0255	37.71	3	All full of blow-holes.
2	97.89	1.90	25.00	317.5	1.19	0.23	150.46	37.28	1.0006	572.51	2	
3	96.06	3.76	26.99	247.4	1.25	0.36	156.93	52.99	0.7031	509.96	4	
4	92.11	7.80	12.37	125.6	1.27	0.43	160.01	61.36	0.2189	277.24	4	
5	90.27	9.58	12.34	114.5	1.40	0.54	175.28	72.52	0.1795	274.60	2	
6	87.15	12.77	11.45	100.0	1.46	0.6	182.32	81.32	0.1391	253.61	1	
7	80.95	18.84	1.59	16.3	1.53	0.92	190.15	118.51	0.1040	35.59	3	
8	76.63	23.24	0.15	3.4	0.95	0.95	122.13	122.13	0.00017	3.72	4	
9	69.84	29.88	0.08	1.5	1.5	1.5	17.58	17.58	0.00008	0.63	1	
11	65.33	34.47	0.12	0.75	3.4	3.4	16.44	16.44	0.00004	0.36	1	
12	62.31	37.35	0.08	1.0	1.2	1.2	7.06	7.06	0.00003	0.25	1	
13	56.70	43.17	0.10	1.0	1.45	1.45	8.94	8.94	0.00003	0.41	1	
14	51.62	48.09	0.06	1.0	2.8	2.8	13.54	13.54	0.00003	0.19	1	
15	47.61	52.14	0.09	1.0	3.08	3.08	14.87	14.87	0.00003	0.28	2	
16	44.52	55.28	0.09	0.92	2.48	2.48	23.25	23.25	0.00003	0.53	3	
17	42.38	57.30	0.09	1.65	1.77	1.77	28.11	28.11	0.00007	0.60	3	
18	38.37	61.32	0.08	1.70	1.15	1.15	23.46	23.46	0.00005	0.42	3	
19	34.22	65.80	0.06	1.87	0.66	0.66	16.56	16.56	0.00005	0.31	3	
20	25.85	73.80	0.14	2.34	0.88	0.88	20.97	20.97	0.00011	0.76	4	
21	23.35	76.29	0.57	4.5	1.9	1.9	41.50	41.50	0.00030	2.25	1	
22	20.25	79.63	0.50	5.69	0.98	0.9	22.93	21.32	0.00059	2.07	4	
23	15.08	84.62	2.18	24.83	0.97	0.69	22.80	17.16	0.00092	9.05	3	
24	11.49	88.47	5.70	61.75	1.00	0.60	23.24	15.18	0.0708	23.45	4	
25	8.57	91.39	10.40	131.75	0.98	0.56	22.98	14.51	0.2347	43.85	4	
26	3.72	96.31	18.23	220.5	0.98	0.43	22.83	11.74	0.5677	76.28	2	
27	0.74	99.02	19.63	387.5	0.75	0.26	18.29	8.20	1.3388	90.40	2	
28	0.32	99.46	27.43	535.3	0.66	0.18	16.47	6.89	2.0879	125.99	3	
29	Cast tin.		21.26	556.75	0.48	0.13	12.75	5.78	2.1975	105.45	4	
30	Cast copper.		17.61	153.0	1.38	0.46	143.24	50.63	0.3084	320.35	4	

NOTES ON THE TESTS BY TORSION.

Referring to the above table, it will be seen that the relative strength nd ductility of the various bars in the series, as found by the tests by rsional stress, agree closely with the tests of the same bars by trans- erse and tensile stress. The copper bar No. 30 shows much greater rength and ductility than No. 1, as would be expected from the spongy ructure of the latter.

There is a regular increase of strength in the series to No. 7 (80.95 pper, 18.84 tin), as shown by the other tests. The strength then pidly decreases to No. 12 (62.31 copper, 37.35 tin), the weakest of the ries. The same general weakness and irregularity are observed in the ars from No. 12 to No. 20 (25.85 copper, 73.80 tin), as was shown in the sts by tensile and transverse stress. The second maximum point of rength is again given by No. 21 (23.35 copper, 76.29 tin), from which oint the strength regularly decreases to No. 29 (all tin). The curves f strength of the series by tensile and torsional stresses (Plate VIII) how the close agreement of the results of the two kinds of test.

Referring to the autographic strain-diagrams of the tests by torsion Plates XXII to LXXVI) and to the tables of results calculated from he diagram of each piece, the following observations may be noted:

Nos. 1 A, 1 C, 1 D, Plate XXII (cast copper). All of the pieces were ull of blow-holes, and the results are of no value except to show the orthlessness of this metal as ordinarily cast. For the standard tests of ast copper see No. 30.

No. 2, Plates XXII, XXIII, XXIV (97.89 copper, 1.90 tin).—The pieces narked A and B were sound and gave good results. Pieces C and D ontained several blow-holes, and are rejected in the averages as defect- ve. The facts that two of these pieces were stronger than the others, nd that the weaker pieces were taken from the middle portion of the ar show the cause of the defective transverse strength, and show also hat the defects in some of the bars were local and did not extend hroughout the whole length. The pieces A and B show a high de gree f ductility, the total angles through which they were twisted before upture being 296 and 339 degrees respectively.

No. 3, Plates XXV, XXVI, XXVII, XXVIII (96.06 copper, 3.76 tin).—he four pieces tested give results varying from 128 to 181 foot-pounds f torsional moment. The appearance of the fractures does not indicate he reason of the variation. The strongest piece had the greatest duc- lity, and the next to the strongest had the least ductility.

No. 4, Plates XXVIII, XXIX (92.11 copper, 7.80 tin).—The pieces aken from the ends of the bar, marked A and B, gave the same strength, iz, 175 foot-pounds of moment, while the pieces from the middle of he bar marked C and D, gave only 140 and 149 foot-pounds respect- ely. The ductility varied in the same direction as the strength, the ieces from the ends having extensions about twice as great as pieces om the middle.

No. 5, Plate XXX (90.27 copper, 9.58 tin).—Both pieces from the wer half of the bar were defective. The piece marked B had a large avity, about one inch long and nearly half an inch in diameter. The xistence of this cavity was unsuspected before the test was made. The iece marked D had several small blow-holes, and a peculiar dark color, s if oxidized, similar to that which has been noted under the tensile sts of this bar. The pieces A and C were sound, and gave results early agreeing with each other.

No. 6, Plate XXXI (87.15 copper, 12.73 tin).—The torsional strengths of

the four species varied from 134 to 182 foot-pounds. The fractures show the cause of the difference. The fractures of pieces from the upper half of the bar, A and C, show the same separation of metals which has been remarked upon in the transverse test of this bar. There are two distinct colors, golden-yellow and silver-white, mingled throughout the surface of fracture, showing liquation of the metal into two distinct alloys. The piece marked D, from the upper end of the lower half of the bar, also showed this separation, but in a much less degree, or rather, the intermixture of the two colors was much closer and finer, so that a close inspection was required in order to recognize it. The fracture was somewhat similar to that of the tension test-piece, No. 6 B. In the torsion piece, from the lower end of the bar No. 6 B, liquation was not observable, and the fracture appeared quite homogeneous, and of a uniform golden-yellow color, similar to that of No. 5 A or C. As might be expected, this piece was the strongest of the four, its maximum torsional moment being 182 foot-pounds, while those of the pieces A, C, and D were 145, 144, and 134 foot-pounds respectively.

The ductility of this piece (No. 6 B) was also considerably greater than that of either of the others. The shapes of the surfaces of fracture by torsional stress of the four pieces also illustrate in a marked degree their differences of properties. The pieces A and C have the irregular diagonal or conoidal fracture which is characteristic of all brittle metals and of those having only a limited amount of ductility, such as cast iron (Fig. 9), while the fracture of piece B is nearly smooth, and lies in a plane perpendicular to the axis of the specimen.

Fig. 9.

Fig. 10.

This fracture is characteristic of wrought iron (Fig. (10), and of all metals which are similarly ductile. The fracture of the piece marked D was partly diagonal and partly perpendicular to the axis, showing a structure with a character between those of pieces A and B.

The analyses of the turnings from the upper and lower halves of the bar do not show any variation in composition which can account for the variation in structure or in strength. The composition of the original mixture was 86.57 copper, 13.43 tin, and the analyses gave for the upper half of the bar 87.15 copper, 12.69 tin, and for the lower half 87.15 copper, 12.77 tin. The difference in structure is possibly accounted for by the more rapid cooling of the metal at the lower end of the mold, which cool-

ıg would prevent a separation of the metals, or it may be that the greater ıressure sustained by the molten metal at the bottom of the mold pre-ented such separation and rendered the metal more compact.

The liquation which is observed in this bar appears to be of a differ-nt character from that of bars Nos. 14 and 17, in which the upper end ıf the bar contained more copper and the lower end more tin. The vari-tion of composition between the upper and lower halves of bar No. 14 vas as great as 24 *per cent.*, and from the appearance of the metal in lifferent portions of this bar, it was evident that the percentage of cop-ıer increased gradually from the bottom to the top, and in no part of he bar was there any appearance of a mottled mixture of two colors, as n bar No. 6.

The tests by transverse stress showed that bar No. 6 had a much less ransverse strength than either No. 5 or No. 7, and if introduced in the urve of tests by transverse stress, would make a break in its regularity. The fact that the torsion piece, No. 6 B, of the same composition as the other pieces from the bar, had such a difference in structure, color, strength, and ductility, shows that the weakness of the bar, as tested by transverse stress, is not a necessary accompaniment of its composition, and it, no doubt, would have given much higher results if the whole bar had been cooled in exactly the same manner and subjected to the same pressure as the bottom of the bar.

In compiling the table of average results of torsion tests given above, the results of the tests of the pieces A, C, and D are rejected as defective, and the piece B is considered the only sound piece from the bar.

The curve plotted from this table (Plate III) then shows a regular in-crease from No. 1 to No. 7 (all copper to 80.95 copper, 18.84 tin), without any such break as it would have if the three pieces from the upper por-tion of bar No. 6 were admitted in the averages.

No. 7, Plate XXXII (80.95 copper, 18.84 tin).—The piece from the lower end of the bar No. 7 B was found, upon testing, to contain a large cavity, similar to that in No. 5 B. The result of the test of this piece ir therefore omitted from the averages. The other pieces, A, C, and D, were sound and gave good results, and agree with the transverse and tensile tests in showing the bar to be the strongest of the series, but as hav-ing very little ductility.

No. 8, Plate XXXII (76.64 copper, 23.24 tin).—The four pieces all gave good results. By inspection of the diagrams of these pieces, it will be observed that the elastic limit was not reached till fracture took place, as each diagram is nearly a straight line, slighly inclined from the verti-cal instead of being a curved line gradually approaching the horizontal, such as was given by all the more ductile pieces. These diagrams cor-respond with the curves plotted from the results of the transverse tests (Plate XVI), which also are nearly straight lines from the beginning of stress to the point of fracture, and fail to show an elastic limit, frac-ture apparently occurring before passing that limit. This composition, though somewhat hard and brittle, works very well in the lathe or planer.

The composition 75.00 copper, 25.00 tin is used by the Messrs. Perkins for the piston-rings of their high-pressure steam-engines without lubri-cation.

No. 9 to No. 17, Plates XXXII, XXXIII, XXXIV (29.89 to 57.30 tin).—The bars No. 9 to No. 17 inclusive were so very hard that it was impos-sible to turn torsion pieces in the lathe to standard size without risk of breaking them. They were therefore only turned to cylindrical form, with diameters varying from 0.890 to 0.970 inch. Many of the pieces

broke in the lathe even before the cylindrical form was reached, and thus, in many cases, only one or two pieces could be obtained from a bar. A few of the pieces, Nos. 9, 10, 11, and 12, could not be cut at all with the hardest steel tool, and were ground on a small emery wheel.

On account of the great lack of strength of these pieces, the 100-pound weight was removed from the arm of the machine, and the weight of the arm alone, or, in some cases with a 30-pound weight attached, was used to measure the resistance. The diagrams of strain of all these pieces are similar in character, being almost straight lines, very nearly vertical, and showing no elastic limit or point of change of direction of the line towards the horizontal.

The torsional moments of the pieces, whose diameters are larger than the standard size (0.625 inch), were reduced to the equivalent moments of pieces of standard size by dividing them by the ratio of the cubes of the diameters of the pieces to the cube of 0.625, since the resistances to rupture by torsion of pieces of different diameters vary as the cubes of the diameters. Thus reduced, the maximum torsional moments of these pieces range from 7.06 to 29.60 foot-pounds; or they were nearly from $\frac{1}{30}$ to $\frac{1}{7}$ as strong as the strongest piece tested, No. 7 C.

The resiliences, *i. e.*, the amounts of energy expended or work done in producing the rupture of these brittle pieces, are not reduced to the equivalents of pieces of standard size, since the relation between the diameters and resilience was undetermined. The figures of resilience which are given in the tables do not represent the moduli, but are the absolute resiliences of the pieces tested. The resilience reduced to a modulus for the standard diameter would be much smaller.

The enormous difference in resilience between these brittle specimens and those more ductile is seen, even without reducing them to a common standard.

The resiliences of the brittle pieces of large diameters vary from 0.19 to 0.92 foot-pounds, while that of No. 3 A, the most resilient piece of standard size, is 936.56 foot-pounds.

No. 18, Plate XXXIV (38.37 copper, 61.32 tin).—Three torsion pieces were obtained from this bar, of which two were turned to the standard size. The diagrams show the same distinguishing characteristics as those of Nos. 9 and 17, except that a slightly greater inclination from the vertical is to be noted, indicating less stiffness.

No. 19, Plate XXXIV (34.22 copper, 65.80 tin).—Three torsion pieces were tested which gave the characteristic diagrams of weak and brittle materials, but the piece marked B was nearly three times as strong as the pieces marked A and D. This is readily accounted for on examining the appearance of the fracture. It was coarsely granular, while the fractures of the pieces A and D were coarse and laminated or crystalline. This difference of structure does not appear to be due to a difference of composition, but it may be a consequence of a difference in the rate of cooling of the upper and lower ends of the bar, or of a difference in pressure in the liquid metal, such as has been observed in the notes on the test of No. 6 B.

No. 20, Plate XXXIV (25.85 copper, 73.80 tin).—Four pieces were tested, which exhibited the same differences in strength and in structure that were shown in No. 19. The piece A had a large prismatic crystalline or laminated structure, and the piece gave a torsional moment of only 10.84 foot-pounds. The piece C had a crystalline structure, but the crystals were very much smaller, were more confused and less well-defined. The torsional moment was 25.35 foot-pounds. The piece D was different from either, being rather open and granular and of a little

darker color than either of the others. It was also very weak, giving a torsional moment of only 12.44 foot-pounds. The piece B again differed from all the others. It had a very close, fine, granular structure, and in color similar to those of A and C. There was a blow-hole in the center of the specimen, about ½ inch long and 0.15 inch in diameter, but notwithstanding the blow-hole it was much the strongest of any of the four pieces, having a torsional moment of 35.44 foot-pounds.

These differences in structure are not shown by the analyses to be due to liquation, as there is but little difference in composition of turnings from different portions of the bar, and similar appearances of color and structure are observed in pieces which are known to vary in composition as much as 10 per cent. In the grayish-white alloys the prismatic crystalline structure is usually found in the upper portion of the bar, and it is always accompanied by deficiency in strength. It is perhaps due to slow rate of cooling, or to lighter pressure than is sustained by the metal at the bottom of the mold.

No. 21, Plate XXXIV (23.35 copper, 76.29 tin) had a cavity *extending through its whole length* except five inches of the upper end. A torsion piece could only be obtained, therefore, from this upper portion. It exhibited a torsional resistance of 41.50 foot-pounds, which is greater than that of any piece from No. 9 (69.84 copper, 29.89 tin) to No. 29 (all tin). This gives a second maximum point of strength in the series, and one corresponding to those obtained by tensile and transverse stress. The structure was similar to that of the piece No. 20 B.

No. 22, Plate XXXIV (20.25 copper, 79.63 tin).—Four pieces were tested, showing resistances varying from 12.24 to 33.43 foot-pounds of torsional moment. The fractures were all confusedly crystalline, showing some differences in structure, which may account for their differences in strength. The strongest piece, No. 22 B, had an angle of torsion of 10 degrees, which is greater than that of any piece between No. 8 and No. 22, and marks the beginning of the ductile specimens at the latter end of the series. From No. 22 there is a regular increase of ductility to No. 29 (all tin), which is the most ductile of the series.

No. 23, Plate XXXV (15.08 copper, 84.62 tin).—Three pieces were tested, which gave diagrams nearly similar, the strength ranging from 20.31 to 26.36 foot-pounds, and the angles of torsion from 22 to 26.5 degrees. As shown by the diagrams, each piece twisted through several degrees after reaching its maximum resistance, the last portion of the diagram being a horizontal straight line. This appears to be a peculiarity of the more ductile white alloys. The yellow ductile metals do not usually reach their maximum resistances till nearly at the point of fracture.

No. 24, Plates XXXV, XXXVI (11.49 copper, 88.47 tin).—Four pieces were tested, giving torsional moments from 21.32 to 25.35 foot-pounds. Great differences in ductility were observed among these pieces, No. 24 A having an angle of torsion of 16 degrees and No. 24 C an angle of 109 degrees. There was nothing in the appearance of the fracture which would indicate the cause of these differences.

No. 25, Plates XXXVII, XXXVIII (8.57 copper, 91.39 tin).—Four pieces were tested, which gave diagrams nearly similar in shape. The pieces A, C, and D showed almost the same strength, viz, 21.32, 20.31, and 20.91 foot-pounds respectively, with corresponding angles of torsion of 153, 123, and 148 degrees. No. 25 B had much greater strength, viz, 29.39 foot-pounds, and a smaller angle of torsion, viz, 102 degrees. Its greater strength is partly accounted for by the method of test. As shown in the diagram, the speed of the handle of the machine was increased in the latter portion of the test, which at once caused an in-

creased resistance, as shown by the rise of the diagram. This increase of resistance to rapid motion uniformly took place in all the white ductile alloys, and agrees with that which has already been noted under the transverse and tensile tests.*

No. 26, Plates XXXIX, XL (3.72 copper, 96.31 tin).—Four pieces were tested, but two are rejected from the table of averages on account of the existence of blow-holes, which were found in the center of the pieces after testing them. The remaining pieces B and D exhibited resistances of 19.30 and 26.36 foot-pounds, and gave angles of torsion of 251 and 190 degrees, respectively. The test of No. 26 D was purposely made rapidly, and its increased resistance is thus accounted for. The increase of resistance is apparently connected with a decrease of ductility in this piece as well as in No. 25 B, but in some other tests of ductile metals this did not always seem to be the case.

No. 27, Plates XLI, XLII, XLIII (0.74 copper, 99.02 tin).—Four pieces were tested, of which two, A and D, are rejected from the averages on account of blow-holes. The pieces B and C gave maximum torsional moments of 17.28 and 19.30 foot-pounds, with angles of torsion of 362 and 412 degrees, respectively. Referring to the diagram of No. 27 C, it will be seen that its maximum resistance took place only at a point where there was a rapid motion of the arm for an instant, and that at every other part of the diagram the resistance was less than that of No. 27 B, which was tested with a uniform slow motion. Although the ductility of No. 27 C is the greater, its resilience is less, which shows that it had a slower mean resistance. At different points of this test the rate of motion was changed, and at times stopped entirely. At one time the piece was left under stress for 16 hours, and at other times for the spaces of 10 minutes, 2 minutes, and 1 minute. At each of these rests the resistance of the piece decreased, as is shown by the fall of the diagram. A rise of the diagram is seen to take place whenever there is an increase in the rate of motion. This test exhibits in a very marked degree the influence upon ductile metals both of rapid and slow distortion, and of decrease of resistance to static load when left for a length of time.†

No. 28, Plates XLIV, XLV, XLVI, XLVII (0.32 copper, 99.46 tin).—Four pieces were tested. The test of the piece A was made with the 100-pound weight on the arm of the machine, and consequently the ordinate of the diagram became so small that too great error in measurement may exist, and the test is therefore rejected from the averages. The other three pieces were tested without the weight on the arm, with a uniform slow motion, and gave good results, showing considerable uniformity, both in strength and ductility.

No. 29, Plates XLVIII, XLIX, L, LI (all tin).—Four pieces were tested, the pieces A, B, and C with ordinary uniform slow motion, and the piece D with a much slower motion. The latter piece was also left under stress at different times for 40 and for 1, 2, and 4 hours. The first three pieces showed great uniformity, their diagrams being almost exactly similar. The latter, in consequence of the very slow motion, exerted a much smaller resistance, and, when left under stress, a decrease of resistance.

No. 30, Plates LII, LIII (all copper).—Four pieces were tested, all giving good diagrams. The torsional moments varied from 127 to 155 foot-pounds, and the angles of torsion from 105 to 177 degrees. All these tests show this bar of copper to be an excellent piece, confirming the results of the transverse and tensile tests. Comparing the results of

* See papers by the writer, Trans. Am. Soc. Civil Engrs., 1873–'76.
† See papers by the writer, &c.

the tests of the torsion pieces of No. 30 with those of the other copper piece, No. 1, a very great contrast is seen. The torsional moments of the latter were only 57 to 75 foot-pounds, and the angles of torsion only 26 to 49 degrees. The fractures of No. 30 were all compact and homogeneous, while those of No. 1 were all full of blow-holes.

TESTS BY COMPRESSION.

A number of pieces were taken from the broken tension-test specimens and turned into small cylinders to be tested by compressive stress. The size of these pieces was very accurately 2 inches in length and 0.625 inch in diameter. The ends were carefully made plane surfaces, perpendicular to the axis of the cylinder.

Nos. 1 D, 25, 26, 27, and 28, were tested in a compression attachment to the Riehlé testing-machine (Fig. 6, p. 314), described in connection with the tensile tests, and the amounts of compression were measured by the apparatus (Fig. 13, p. 348) used in measuring tensile elongations in the second series. For these compression tests the level was removed, the arm which supported the level fixed, and a battery and signal connected to determine the point and instant of contact of the end of the micrometer-screw by the passage of a current of electricity.

All other tests were made on the testing-machine, of 100,000 pounds capacity, in use by the Ordnance Bureau, U. S. A., at the Army Building, New York City. In this machine the stress is applied by means of a lever operated by hand through a system of spur-gearing with a screw, and is measured by a combination of levers. A similar machine, designed by Major Wade, is described in a Report of Experiments on Metals for Cannon, by officers of the Ordnance Department, U. S. A., 1856.

On account of the small lengths of the specimens, it was difficult in this machine to make direct measurements of the amounts of compression. An approximation to the amount was derived from noting the number of revolutions of the handle necessary to produce a certain compression.

It was found that $47\frac{1}{4}$ turns of the handle were required to cause one turn of the screw, which raised the main lever of the machine. The arms of the lever were as 10 to 1, and the pitch of the screw which elevated it was 0.4 inch. From these data it is found that one turn of the handle should produce a compression of the test specimen of 0.000846 inch.

From this is to be subtracted an error due to the spring or elasticity of the machine itself. A close approximation to the actual amount of this error was obtained as follows:

The piece No. 8 B was placed in the machine, and after a few hundred pounds pressure was applied for the purpose of taking up backlash in the gearing, it required 296 turns of the handle to produce a stress of 32,000 pounds. At the same time the distance between the pressure-plates at the top and bottom of the piece, as measured by a scale divided to $\frac{1}{100}$ of an inch, was 1.83 inches, indicating an actual compression of the piece of 0.17 inch. The calculated compression, including the error, was $296 \text{ turns} \times 0.000846 = 0.250416$ inch. The error is, therefore, $0.250416 - 0.17 = 0.080416$ inch.

We may safely assume that the error due to the elasticity of the parts of the machine is proportional to the stress, and hence $\frac{0.080416}{32000} =$

0.0000025 is the error of the calculated compressions for each pound of stress.

This comparison of calculated with actual compressions was repeated a great number of times with nearly similar results, and the averages of the most reliable observations gave the same figure.

Table No. V, giving the results of all the tests by compressive stress, is appended. The figures given in the table as the compression of the pieces tested in the testing-machine of the Ordnance Bureau were calculated from the number of turns of the handle required to produce the corresponding stress, in the manner above stated, using the formula

$$C=0.000846\ N-0.0000025\ P$$

where C is the amount of compression in inches, N the number of turns of the handle, and P the applied stress in pounds.

The following table, V, presents a condensed summary of the results of these experiments. The results are also combined with those of the second series in the plotted curves of Plate IV.

TABLE V.—TESTS BY COMPRESSIVE STRESS.

First Series.—Alloys of Copper and Tin.

No.	Composition by analysis.		Load per square inch causing a compression of—			Maximum load per sq. inch.	Total compression produced by maximum load. Parts of original length.	Crushing strength per square inch.	Remarks.
	Copper.	Tin.	5 per cent.	10 per cent.	20 per cent.				
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	
1	Cast copper.		26,000	39,000	51,000	74,968	.4480	39,000	Flattened.
1 D	..... d		33,000	45,500	58,671	78,228	.4339	45,500	Do.
2	97.83	1.92	29,335	34,000	46,000	46,263	.3680	34,000	Do.
3	95.96	3.80	39,200	42,048	52,152	52,152	.3025	42,048	Do.
4	92.07	7.76	31,500	42,000	65,000	84,095	.4575	42,000	Do.
5	90.43	9.50	32,000	38,000	60,000	61,930	.3355	38,000	Do.
6	87.15	12.77	39,000	53,000	80,000	89,636	.3860	53,000	Do.
7	80.99	18.92	65,000	78,000	103,489	103,489	.2030	78,000	Do.
8	76.60	23.23	101,044	.....	.....	114,081	.0905	114,081	Crushed.
9	69.90	29.85	.....	.....	.....	146,676	.0350	146,676	Do.
11	65.31	34.47	.....	.....	.....	84,747	.0285	84,747	Do.
12	61.83	37.74	.....	.....	.....	39,114	.0175	39,114	Do.
15	47.72	51.99	.....	.....	.....	84,747	.0215	84,747	Do.
16	44.62	55.15	.....	.....	.....	35,854	.0066	35,854	Do.
17	38.83	60.79	.....	.....	.....	39,114	.0205	39,114	Do.
18	38.37	61.32	.....	.....	.....	29,335	.0145	29,335	Do.
19	34.22	65.80	19,557	.....	.....	19,557	.0555	19,557	Do.
20	25.12	74.51	17,927	17,927	17,927	17,927	.2805	17,927	Do.
22	20.21	79.62	16,297	16,297	16,297	16,297	.2905	16,297	Do.
23	15.12	84.58	6,519	6,519	6,519	9,452	.5135	6,519	Flattened.
24	11.48	88.50	10,104	10,104	10,104	14,016	.5040	10,104	Do.
25	8.57	91.39	6,500	.....	.....	9,778	.0558	9,778	Do.
26	3.72	96.31	6,519	6,519	6,519	9,778	.3422	9,778	Do.
27	0.74	99.02	6,519	6,519	6,519	9,778	.3632	9,778	Do.
28	0.32	99.46	6,519	6,519	6,519	9,778	.3760	9,778	Do.
29	Cast tin.		6,030	6,400	6,519	7,497	.4445	6,400	Do.
30	Cast copper.		34,000	42,000	58,000	71,709	.3210	42,000	Do.

NOTES ON THE TESTS BY COMPRESSION.

The more ductile alloys, No. 1 to No. 7 (all copper to 80.95 copper, 18.84 tin), and No. 23 (15.08 copper, 84.62 tin) to No. 30 (all copper), were not crushed or broken by any stress which could be applied to them, but

ither bent after sustaining a certain degree of compression, or retaining vertical position, increased in diameter as the decrease in length took lace, and gradually flattened. Some of the pieces were in this manner ompressed to less than one-half of their original lengths, the resistance o further compression always increasing. When the bending took place, he piece under compression would, in some cases, take such a position s to gradually diminish in resistance to stress, the pressure-plates touching only on the edges of the upper and lower surfaces of the piece.

The actual "crushing strengths" of the ductile metals, therefore, cannot be stated; but for purposes of comparison the crushing strength is assumed to be that which corresponds to a compression of one-tenth of the original length. In the above table, therefore, the figures in the column headed "crushing strength" represent, in the cases of ductile metals, the loads per square inch necessary to produce compressions of 10 per cent. of the original lengths.

All the brittle alloys, and some of those possessing certain limited amounts of ductility, No. 8 (76.64 copper, 23.24 tin) to No. 18 (38.37 copper, 61.32 tin) inclusive, broke suddenly when their maximum resistances were reached, and the figures for their crushing strengths are, therefore, the actual values. In these, the figures for "total compression produced by maximum load" are the calculated compressions at the instants of the sudden breaking. In the cases of the others, the figures in the same columns are the total compressions which were actually given to the pieces without breaking them and include the shortening of the piece by bending, but are not the total amounts of compression which might have been produced if the test had been continued further.

The loads per square inch, producing compressions of 5 per cent. and 20 per cent., are also given in the table for purposes of comparison.

By inspection of the table and the curves (Plates IV, VII), and comparing the results with those of the transverse, tensile, and torsional stresses, some important facts are observed. Assuming, as already stated, that the crushing strength of a ductile metal is the load necessary to produce a compression of one-tenth of the original length, and that of a brittle metal is the load actually causing fracture, it is seen that the maximum and minimum compressive strengths are not found in the compositions which exhibited maximum and minimum strengths by the other three methods of test. It has already been observed that the relative strengths of the various alloys, as shown by the other three methods of test, are similar. This is not the case with the compressive tests.

The maximum crushing strength is given by No. 9 (69.84 copper, 29.89 tin), which gave results much nearer the minimum under the other forms of test. The minimum crushing strength is found in tin, which was superior to several of the brittle alloys in other methods of test, and which alloys greatly surpassed it in tests by compression. It appears that the resistance to compression has an entirely different nature from resistance to tension, and that the tin qualities have no apparent relation to each other.

The compression pieces, No. 1 (all copper) to No. 5 (90.27 copper, 9.58 tin), and No. 30 (all copper), give results very nearly alike, varying from 34,000 to 42,000 pounds per square inch to produce a compression of one-tenth of the original length. From No. 6 (87.15 copper, 18.84 tin) to No. 9 (69.84 copper, 29.89 tin) there is a rapid increase up to 146,676 pounds per square inch. From this point a decrease takes place to No. 29 (all tin). This decrease is somewhat irregular, No. 11 (65.34 copper, 34.47 tin) and No. 15 (47.61 copper, 52.14 tin) giving a crushing strength of 84,747, and No. 12 (62.31 copper, 37.35 tin) only 39,114 pounds. It

would be necessary to make a greater number of tests before attempting to explain this irregularity, but it does not seem improbable that it may be a peculiarity of these compositions, since No. 12 was very different in color from both No. 11 and No. 15, and had the highest density of the series, a density much higher than that of No. 15. It may be that an alloy of nearly the composition of No. 12 represents a *second minimum* point of compressive strength in the curve, and an alloy near No. 15 may give a *second maximum* point, as No. 21 (23.35 copper, 76.29 tin) gave a second maximum by the other tests and No. 29 (all tin) a second minimum. It will require further tests, however, to settle this point definitely.

The following phenomena were observed in connection with these tests in addition to those noted in the tables. The behavior of the test-pieces is clearly shown in the plotted curves, Plate XX.

No. 1 (all copper).—This piece had a few small blow-holes on the turned surface, but appeared to be sounder than most of the bar from which it was taken. It was noticed to have taken a scarcely perceptible bend when a stress of 29,000 pounds per square inch was reached after a compression of 6.4 per cent. As the stress increased the bending became more readily observable, and when the piece was removed, after a compression of 44.8 per cent., it was very considerable. The piece had then become much distorted, the bend taking a special direction, and the diameter had increased to about 0.77 inch, varying slightly in different portions of the length. The amount of compression began to vary more rapidly than the stress, after a stress of 13,000 pounds per square inch had been applied, showing apparently an elastic limit. It is probable, however, that this point does not truly represent the limit of elasticity, but was the point at which the bending commenced, although its effect was not perceptible till a much higher stress had been applied, and that, beyond this point, the figures under the column headed "compression" really represent a shortening of the vertical distance between the ends of the specimen by the combined action of bending and compressive stresses.

No. 1 D (cast copper).—A second specimen, taken from the D end of the bar, was subsequently tested in the compression testing machine. The results as plotted show a curve similar to that of the one just noted, but the resistances to compression are uniformly higher. The maximum compression obtained was 0.8678 inch under a pressure of 78,228 pounds per square inch. A pressure of 81,487 pounds per square inch was next applied, which broke the specimen into three parts. Wedge-shaped pieces, with bases the full diameter of the test-piece, separated at top and bottom, the planes of separation inclining and meeting at the middle of one side. The three pieces remained welded together by the pressure.

No. 2 (97.83 copper, 1.92 tin).—The amount of compression was nearly proportional to the stress up to about 25,000 pounds per square inch. At 29,000 pounds per square inch the bending of the piece became perceptible, and at that point a continuance of the stress for about one minute produced an evident increase of the compression. From 29,000 to 46,000 pounds the compression again varied nearly as the stress, but the ratio of compression to stress was much greater than in the beginning of the test. At 46,000 pounds the piece had a marked double curvature in one plane, and appeared to slide on the pressure-plates, so that the pressure was applied only on opposite edges of the upper and lower surfaces of the specimen instead of evenly over the whole surface. After this point the resistance rapidly decreased, not from any giving way of any fibers of the material, but from the specimen taking a posi-

tion which was unfavorable to resistance to stress, and bending then took place rapidly without any further compression. The resistance fell to 6,000 pounds per square inch, when the piece finally only touched the pressure-plates with the edges of its upper and lower surfaces. The diameter of the specimen when removed had increased to 0.71 inch.

In the plotted table of curves (Plate XX) the curve of this specimen is seen to attain its maximum ordinate at 46,000 pounds per square inch, and after that point to rapidly approach the axis of abscissas. It is to be noted in all these tables and curves which show a decrease of resistance after reaching a maximum that this decrease is due to the bending of the specimen and not to decrease of power to resist actual compression.

No. 3 (95.96 copper, 3.80 tin).—The action of this piece under test was similar to that of No. 2. The compression was proportional to the stress up to 32,000 pounds per square inch. Bending first became perceptible at 40,000 pounds, and soon afterwards a decrease of resistance took place. The piece then seemed, for a short time, to attain a position in which it could offer greater resistance to increased stress, and the maximum was reached at 52,000 pounds. The resistance then decreased rapidly till the piece was removed. Its axis became a line of double curvature like that of No. 2, and the piece finally touched the pressure-plates only with the edges of its upper and lower surfaces. When removed the diameter was found to have increased to 0.68 inch.

No. 4 (92.07 copper, 7.76 tin).—This piece bent under stress with a double curve similar to that of No. 3. The *apparent* elastic limit was reached at 26,000 pounds, and bending was first observed at 29,000 pounds; the maximum resistance was reached at 84,000 pounds, after which it rapidly decreased by reason of the bending. When removed, the diameter was found to be increased to 0.73 inch.

No. 5 (90.43 copper, 9.50 tin).—The compression was proportional to the stresses only to 20,000 pounds per square inch, but bending was not observed until 32,000 pounds had been reached. The bending took place in one plane, giving a double curvature, and increased rapidly, so that the maximum resistance was reached at 61,930 pounds per square inch. The resistance then decreased rapidly to 13,000 pounds, when the piece had taken such a position that it ceased to resist further compression, and slipped out from between the plates. The diameter was found to have increased to 0.69 inch.

No. 6 (87.15 copper, 12.77 tin).—This piece was taken from the bottom of the bar, where the metal was found by the torsion tests to be the most homogeneous. The piece bent in the same manner as those described above, but in addition to the bending, the surface of the piece became curiously distorted, as if small patches of the surface were softer than other portions, and these resisted compression less than the harder portions. The compression was proportional to the stress to about 30,000 pounds per square inch. Bending was first observed at 35,000 pounds, after which the further compressions were again proportional to the stresses, the ratio of compression to stress being greater than in the first part of the test. The maximum resistance was reached at 89,000 pounds per square inch, after which the resistance decreased, by reason of the bending, to 32,000 pounds, when the piece slipped out from between the pressure-plates. The diameter was increased to 0.70 and 0.73 inch as measured in different portions of the length.

No. 7 (80.99 copper, 18.92 tin).—The compression remained nearly proportional to the stress up to about 60,000 pounds per square inch. A very slight bending was observed at about 67,000 pounds, the piece taking a double curve in one plane. The maximum resistance was

reached at 103,500 pounds per square inch, after which it decreased to 91,000 pounds. A crack then appeared on each of the two convex surfaces of the double curve, and the piece slipped out from between the pressure-plates, at the same time crushing off small pieces of the metal at the edges of the upper and lower surfaces which last touched the pressure-plates. The diameter was increased to 0.67 inch.

No. 8 (76.60 copper, 23.23 tin).—The compression was proportional to the stress to about 91,000 pounds per square inch, after which the ratio of the former to the latter slightly increased. A very slight bend was observed at 107,000 pounds. The maximum pressure was reached at 114,000 pounds, when the piece suddenly broke diagonally across the middle, after a total compression of 9.05 per cent. In breaking, the diagonal surfaces slipped on one another in such a manner that they became polished. The diameter was uniformly increased to 0.64 inch.

No. 9 (69.90 copper, 29.85 tin).—This piece proved to be the strongest of the series, a stress of 146,676 pounds per square inch being required to produce rupture. The compression remained nearly proportional to the stress throughout the whole test. There was no appearance of bending, and the fracture took place without any warning whatever. The piece suddenly broke into an immense number of small pieces, the largest of which was not larger than a pea. A report like a pistol-shot was made as the piece broke. The record of the test shows a calculated compression of 3.50 per cent. From the nature of the material it seems possible that this figure may be too high.

No. 11 (65.31 copper, 34.47 tin).—The compressions were nearly proportional to the stresses throughout the test. The piece broke suddenly at 84,747 pounds per square inch, the upper portion of the piece flying into fragments.

No. 12 (61.83 copper, 37.74 tin).—This piece broke nearly in the same manner as No. 11, but sustained less than one-half the amount of stress—39,000 pounds.

Nos. 10, 13 and 14 were not tested, as they broke in the lathe while being turned.

No. 15 (47.72 copper, 51.99 tin).—This piece gave the same result as No. 11, breaking at 84,747 pounds per square inch. It broke suddenly into several large fragments.

No. 16 (44.62 copper, 55.15 tin).—This piece sustained a stress of only 35,854 pounds per square inch. The fracture took place suddenly, and it appeared as if in the upper end of the specimen a cone-shaped wedge was formed, which split open the metal on all sides, and produced a vertical crack through the center of the piece, reaching to the bottom.

No. 17 (38.83 copper, 60.79 tin).—Two pieces were tested from this bar, which gave similar results, breaking at 39,000 pounds per square inch. The fractures were of the same character as that of No. 16.

No. 18 (38.37 copper, 61.32 tin).—This specimen proved to be much weaker than any previously tested, breaking at 29,000 pounds per square inch. It broke by wedge-shaped fragments flying off the upper end. The compression was proportional to the stress up to the breaking point.

No. 19 (34.22 copper, 65.80 tin).—This piece was even weaker than No. 18. It reached a maximum resistance at 19,500 pounds per square inch after a compression of 1.20 per cent., the compression being proportional to the stress at this point. The resistance to stress then decreased rapidly, the piece bulging out on all sides about a diagonal plane of fracture near the middle. Several cracks soon appeared around the point of bulging, and the resistance decreased to 8,800 pounds per

quare inch, when the piece was removed. The total compression was .55 per cent. The diameters of the ends of the specimens, which were pparently not affected by the bulging in the middle of the piece, had ncreased to 0.630 inch.

No. 20 (25.12 copper, 74.51 tin).—This piece reached a maximum re-istance at 17,900 pounds per square inch, the compression being nearly proportional to the stress, after which it rapidly decreased to 2,900 pounds. During this decrease a remarkable phenomenon was observed. A diagonal crack appeared at the top of the specimen, reaching from one edge of the upper surface to a point on the cylindrical surface opposite to this edge, and about ¾ inch from the top. The wedge-shaped piece thus fractured from the specimen was gradually forced along the line of fracture till it was nearly pushed off on one side, but still remained attached, as if by "cold welding." When this partly separated piece first started off from the remainder of the specimen, the larger part of the stress appeared to be resisted by only a small portion of the upper surface, and the resistance consequently decreased to 2,900 pounds per square inch. This portion of the upper surface was then gradually flattened, and so apparently better fitted to resist a further amount of compression. As the compression increased from 6.80 to 25.60 per cent. the resistance again increased from 2,900 to 10,267 pounds. By this time a second but much smaller wedge had been forced off on the side opposite the larger one, and the action above described was repeated. A large number of still smaller wedge-shaped pieces were then partially detached and surrounded the whole of the upper end of the specimen. After reaching the second maximum, 10,267 pounds, the resistance began to decrease again, but the specimen was removed after a compression of 28.05 per cent. with the first wedge-shaped piece still attached to its upper end. The diameter of the lower portion of the specimen had increased only to 0.629 inch when it was removed. Fig. 11 shows the appearance of this specimen after its removal.

FIG. 11.

No. 22 (20.21 copper, 79.62 tin).—The compression continued nearly proportional to the stress to about 12,000 pounds per square inch. At about 16,000 pounds a bend in the specimen was observed, and at the same time the resistance to stress decreased, as further compression took place, to 7,000 pounds. The resistance afterward increased to 10,400 pounds per square inch, by reason, probably, of the piece taking a more favorable position to resist bending, and then it again decreased to 1,300 pounds, when the piece had bent so much that it slipped out from between the pressure-plates. The bend took the shape of a double curve in one plane, and a crack appeared on each of the two convex surfaces of the curve in like manner as in No. 7. The diameter of the piece was increased to 0.65 inch.

No. 23 (15.12 copper, 84.58 tin).—This piece behaved in a manner somewhat similar to No. 20. The compression continued nearly proportional to the stress till 6,500 pounds was reached. The resistance then decreased to 4,563 pounds. At the same time a slight bulging took place about half an inch from the bottom. The bulging increased, and the upper portion of the piece apparently crushed out the lower portion, which latter still remained attached to the specimen, as did the wedge-shaped pieces in No. 20. As the compression proceeded the portion of the piece above the bulging appeared to obtain a better bearing, and after the resistance had decreased from 6,519 to 4,563 pounds, it again increased gradually to 9,452 pounds, the piece being then compressed

more than one-half of its original length. The shortening of the piece took place almost entirely by crushing out portions at the lower end, and these portions remained attached to the piece, by what has been termed a sort of "cold welding," till they were separated by other pieces crowding them off. The diameter of the upper end of the specimen was increased only to 0.645 inch (original diameter 0.625 inch).

No. 24 (11.48 copper, 88.50 tin). This piece attained a resistance of 10,104 pounds per square inch with a compression of 6.94 per cent., when a slight double curve was observed and the resistance decreased very slightly. As the compression was continued, the diameter of the piece gradually increased throughout the whole length, and the resistance increased to 14,000 pounds per square inch, when the piece had been compressed more than one-half of its original length. There were no signs of any fracture, and the piece merely flattened out, offering continually greater resistance. The compression could probably have been continued till the piece flattened out to a thin sheet, if the limits of the machine had allowed. When removed, the piece was somewhat irregular in shape, the diameters varying from 0.85 to 0.88 inch.

No. 25 (8.57 copper, 91.39 tin).—A pressure of 65.9 pounds per square inch compressed the specimen 0.1117 inch. The load was increased to 9,778 pounds per square inch, the effect of which was to crack the specimen at top and bottom, forming wedge-shaped pieces, which, however, did not become separated from the mass. The height of the specimen when removed from the machine was 1.06 inches. The section was very irregular, somewhat elliptical in form, and varying in diameter from 0.84 to 0.95 inch.

No. 26 (3.72 copper, 96.31 tin) yielded gradually to the applied stress. At a pressure of 6,519 pounds per square inch the compression was 0.6845 inch; the pressure was increased to 9,778 pounds per square inch and the piece was then removed. Its height had been diminished to 1.01 inches. Its diameter varied from 0.84 to 0.89 inch. The shape of the specimen when removed from the machine was oval. The wrinkled appearance of the sides extending throughout the height of the test-piece was an evidence of the homogeneousness of thealloy. The piece was considerably bent; the directions of the markings or lines showed a tendency to a wedge-shaped separation at the top and bottom. The ductility of the piece, however was too great to permit fracture even under such an amount of compression.

No. 27 (0.74 copper, 99.02 tin) offered a somewhat less resistance to compression than No. 26. A pressure of 6,519 pounds per square inch compressed the piece 0.7264 inch. The pressure was increased to 9,778 pounds per square inch, and the piece then removed. Its height was reduced to 0.95 inch, and its section, which was elliptical though irregular, varied from 0.84 to 0.95 inch. The appearance of the piece was dissimilar to both Nos. 26 and 28, the sides being quite smooth instead of being wrinkled all over its surface as was the case with the other two.

No. 28 (0.32 copper, 99.46 tin) resembled No. 26 very closely in behavior and appearance. The surface was more uniformly wrinkled, showing greater uniformity of resistance to the applied stress. No crack appeared. The compression under a pressure of 6,519 pounds per square inch was 0.752 inch. Under a pressure of 9,778 pounds per square inch the height of the piece was reduced to 0.98 inch. Its section was slightly oval, with diameters averaging from 0.87 to 0.89 inch.

No. 29 (all tin), behaved in all respects like No. 24, showing a gradually increasing resistance until the piece was removed with a compression of nearly one-half its original length. The maximum resistance,

er, was much less than that of No. 24, being only 7,497 pounds uare inch. The diameters of the piece after removal varied from 0.89 inch, and had a nearly elliptical section.

30 (all copper).—The compression continued nearly proportional stress up to about 25,000 pounds per square inch. A very slight n a double curve was then observed. The resistance increased to pounds per square inch at a compression of 32.1 per cent., when ce was removed, its diameters having increased to 0.75 and 0.78 measured in various parts of its length. The bend in the piece t slight, and it would apparently have offered increased resistance her compression indefinitely.

SECOND SERIES.

ALLOYS OF COPPER AND TIN.

second series of copper and tin alloys consisted of twenty bars the same manner as those of the preceding series. The mixtures ade without reference to the chemical equivalents or the atomic s of the metals, but were weighed in even percentages, there a constant difference of 5 per cent. between any two adjoining the series. The first bar contained in the original mixture 97.5 nt. copper and 2.5 per cent. tin; the second, 92.5 copper and 7.5 d so on to the twentieth bar, which contained 2.5 per cent. cop- d 97.5 per cent. tin. The bars were numbered in regular order o. 31 to No. 50.

following table shows the percentage composition of the original e of each bar, its mean composition as subsequently determined lysis of turnings from different portions of the bar, and its mean c gravity:

TABLE VI.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Composition by Original Mixture and Analysis.

Number.	Composition of original mixture.		Mean composition by analysis.		Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	
	97.5	2.5	99.09	0.87	.....
	92.5	7.5	94.10	5.43	8.684
	87.5	12.5	88.40	11.59	8.647
	82.5	17.5	82.72	17.33	8.792
	77.5	22.5	77.56	22.25	8.917
	72.5	27.5	73.89	26.85	8.925
	67.5	32.5	67.87	32.09	8.907
	62.5	37.5	62.42	37.48	8.956
	57.5	42.5	57.87	42.05	8.781
	52.5	47.5	53.46	46.54	8.643
	47.5	52.5	47.27	52.72	8.445
	42.5	57.5	43.96	55.91	8.437
	37.5	62.5	37.10	62.90	8.101
	32.5	67.5	30.76	69.19	7.931
	27.5	72.5	26.62	73.18	7.915
	22.5	77.5	22.10	77.58	7.774
	17.5	82.5	16.70	83.23	7.690
	12.5	87.5	11.68	88.25	7.542
	7.5	92.5	6.05	93.77	7.419
	2.5	97.5	2.11	97.68	7.342

* Second casting; first broke in emery planer.

mixtures for these alloys were carefully weighed on the balance n weighing out the first series, and the melting and casting were cted in the same manner. The cast-iron mold was used for all

the bars, placed in a vertical position, and was heated to prevent sudden chilling of the molten metal while being poured. The mold was heated to nearly red heat in casting the alloys containing the larger percentages of copper, and the temperature was diminished as the percentage of tin increased.

Much less difficulty was experienced in getting good castings at the first melting than in the first series. Bars No, 32 (94.10 copper, 5.43 tin) and No. 37 (67.87 copper, 32.09 tin) only requiring to be melted three times, and all the others only once. Bars No. 38 (62.42 copper, 37.48 tin) to No. 42 (43.99 copper, 55.91 tin) inclusive, however, broke either in the mold while cooling, or on being taken from it, or in subsequent handling. In these cases tests were made of the broken pieces without remelting. The difficulty with No. 32 and No 37 appeared to be caused by pouring the metal in the first meltings at too low a temperature.

In casting bars No. 37 (67.87 copper, 32.09 tin) and No. 39 (57.87 copper, 42.05 tin) a curious phenomenon was observed. After filling the mold with the molten metal a small amount was still left in the bottom of the crucible. This was poured out on the brick floor of the foundry and left to cool. While cooling, the surface of the metal became covered with an aggregation of grayish-colored needle-like crystals, which appeared to *grow* out of the metal and cover it in some places nearly to the depth of one-fourth of an inch. The crystals were removed from the metal and handed to Prof. A. R. Leeds, of the Stevens Institute of Technology, for examination, who made a report in which he calls the substance an artificial mineral. He says concerning it:

> The crystals are needles, not exceeding ¼ inch in length and $\frac{1}{20}$ inch in thickness. Luster adamantine and of great brilliancy. Color, white and transparent. It scratched glass, its hardness being over 6. The specific gravity at 62° Fahr., by the bottle, is 6.019. It will be noted that this is lower than the specific gravity of natural cassiterites which is from 6.4 to 7.1. It glows brilliantly in the oxidizing flame, but gives no evidence of fusion at the terminations of the crystal. It tinges the flame green. With soda it gives a white coating of oxide of tin. Crystals apparently not affected by several hours digestion in hydrochloric and nitric acids.
>
> In chemical constitution it is a stannic oxide, containing a small amount of oxide of copper. The mineral is therefore an artificial variety of crystallized stannic oxide, or cassiterite.

As the temperature of the metal while being poured is supposed to have some influence upon its properties, an attempt was made to obtain the temperatures of casting with this series of alloys by pouring a small portion of the molten metal, just before pouring the remainder into the mold, into a certain weight of water contained in a wooden vessel and noting the increase of temperature of the water caused by the hot metal, and also the weight of the metal poured. This method is the same as that employed by Messrs. Levi and Kunzel in their experiments on phosphor-bronze.*

The data obtained are the weight of the water used, its temperatures before and after pouring the metal into it, and the weight of the metal. The relative temperature is then found from the formula

$$x = \frac{P^1 (t^1 - t)}{P c} + t^1$$

in which P^1 is the weight of the water, P, the weight of metal poured, t the temperature of the water before and t^1 the temperature after pouring, and c the specific heat of the alloy.

The specific heat of the alloy is assumed to be the mean of the specific

* *Comptes Rendus*, Vol. 73, 1871, pp. 530–534.

cats of the component metals, and for these the figures of Regnault re used, viz, copper 0.09515, tin 0.05623.

This formula will not give the actual temperature of casting, since it eglects the fact that the specific heat of a melted metal may not be the ume as that of the solid metal, and since also it neglects the latent heat f fusion of the melted metal, the amount of which is, as yet, unknown. he results, however, will approximately and relatively represent the mperatures, and as the data are all given below, the actual tempera- ures may be calculated whenever the specific heats of the molten alloys nd their latent heats of fusion shall have been determined. The mount of heat transferred to the wooden vessel which contained the ater, was not determined, but the loss is probably so slight that it may e neglected without material influence upon the result. The following able gives the data which were obtained in these experiments, and the emperatures calculated from them:

TABLE VII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Estimated Temperatures of Casting.

Number.	Composition by original mixtures.		Weight of water.	Weight of metal.	Temperatures of water, centigrade scale.			Assumed specific heat.	Calculated relative temperature.	
	Copper.	Tin.			Initial.	Final.	Range.		Centigrade.	Fahrenheit.
			Gram.	*Gram.*						
31	97.5	2.5	907	74	8.3	22.8	14.5	0.094177	1909.9	3469.8
32	92.5	7.5	907	101	12.8	31.7	18.9	0.092231	1871.9	3401.4
33	87.5	12.5	907	149	16.7	42.8	26.1	0.090285	1802.6	3276.6
34	82.5	17.5	907	362	9.4	60.0	50.6	0.088339	1495.1	2723.0
35	77.5	22.5	907	225	15.0	47.5	32.3	0.086393	1554.5	2829.2
36	72.5	27.5	907	157	11.7	33.3	21.6	0.084447	1511.8	2751.8
37	67.5	32.5	907	97	11.1	26.1	15.0	0.082501	1726.2	3148.8
38	62.5	37.5	907	177	10.6	31.7	21.1	0.080555	1373.9	2503.4
39	57.5	42.5	907	129	17.2	32.8	15.6	0.078609	1428.0	2602.4
40	52.5	47.5	907	214	8.3	35.0	26.7	0.076663	1511.1	2751.8
41	47.5	52.5	907	216	12.2	50.5	38.3	0.074717	2205.0	4001.0
42	42.5	57.5	907	328	9.5	47.2	37.8	0.072771	1063.8	1945.4
43	37.5	62.5	907	293	13.9	38.9	25.0	0.070825	1131.7	2067.8
44	32.5	67.5	907	255	8.9	32.2	23.3	0.068879	1756.9	3192.8
45	27.5	72.5	907	85	7.8	18.3	10.5	0.066933	1701.6	3093.8
46	22.5	77.5	907	277	12.2	38.9	26.7	0.064987	1382.7	2519.6
47	17.5	82.5	907	241	15.5	37.2	21.7	0.063041	1331.1	2427.8
48	12.5	87.5	907	104	14.4	22.7	8.3	0.061095	1211.9	2211.8
49	7.5	92.5	907	240	18.9	33.3	14.4	0.059149	956.5	1752.8
50	2.5	97.5	907	154	20.5	27.2	6.7	0.057203	725.3	1337.0

The temperatures of casting of bars No. 32 and No. 37, given above, are those of the third casting, those of the first and second meltings being of no value, as the third casting only was used in the tests.

In the first casting of bar No. 32 (94.10 copper, 5.43 tin), while pour- ng of the metal into the water for the temperature test, an explosion ook place which broke the wooden vessel which held the water, and hrew water and metal about with great violence. It appears probable hat the metal was heated to an unusually high temperature, as in pour- ng other metals when at a dazzling white heat explosions sometimes ook place, but they were usually not violent enough to do more than ake a slight report as the hot metal touched the water.

After the bars were cast they were finished to a rectangular section y grinding on an emery-wheel planing-machine. The brittle alloys gave great deal of trouble by breaking at the ends, and some of them in the iddle, while being ground.

Bar No. 37 (67.87 copper, 32.09 tin) showed a most remarkable degree of brittleness. When cast it appeared perfectly sound, and was taken out of the mold and laid upon a table while still hot. While cooling, a chip of about half an inch long flew off from each of two of the bottom corners of the bars. The fracture had a curved surface, and left the bottom corners rounded. The next day an attempt was made to grind the top of the bar on an emery wheel. Chips of similar curved form instantly flew off from the corners, and on continuing to press the end of the bar against the side of the wheel, resting it at the same time on a table which almost touched the wheel, chips continued to fly from the bar, always breaking with a curved or conchoidal fracture. Finally several chips flew off at once, and left the end of the bar with a rounded point, brilliant and smooth, as if the metal had been melted off. It was then attempted to grind the lower end on a grindstone, but the attempt only succeeded after several chips were broken off, although the greatest care was used in holding it against the stone. The appearance of this bar was almost exactly similar to that of No. 10 (68.58 copper, 31.26 tin) in the first series, which had nearly the same composition.

Bar No. 38 (62.42 copper, 37.48 tin) broke into three pieces while being ground, and the two fractured surfaces showed that liquation had taken place, which was subsequently confirmed by analysis. The upper fracture, 9 inches from the top of the bar, was smooth, conchoidal, and brilliant silver-white in color, like bar No. 37 (67.87 copper, 32.09 tin), while the fracture at the lower part of the bar, 5 inches from the bottom, was dark gray, radiated and crystalline, so different from the first that it indicates an entirely different character of metal. Fractures produced during the tests showed that the change from one appearance to the other was gradual, and that there was apparently a gradual increase in the percentage of copper in the bar from bottom to top. This phenomenon resembles that shown by bars No. 14 (51.62 copper, 48.09 tin) and No. 17 (42.38 copper, 57.30 tin) of the first series, both of which contained less copper than No. 38.

No. 39 (57.87 copper, 42.05 tin) and No. 40 (53.46 copper, 46.54 tin) also broke in handling, but did not exhibit any appearance of liquation. The fractures of No. 39 were all similar to that of the lower part of No. 38.

TESTS BY TRANSVERSE STRESS.

Second Series.—Alloys of Copper and Tin.

The bars, after having been prepared by grinding, were then tested by transverse stress.

The apparatus used was the testing machine of the Mechanical Laboratory of the Stevens Institute of Technology mentioned on page 313 as having been used in the test of bar No. 30. A cut of this machine is shown below.

The apparatus consists of a combination platform-scale of 4,000 pounds capacity, having a platform 5 feet in length and 3½ feet in width, carrying a heavy cast-iron base-plate, C, 5 feet long, on which are mounted two heavy standards, or supports, D D, twelve inches high, which slide along in a groove in the base-plate C, and may be clamped at any point. These supports are level on their upper surfaces, and carry two rollers upon which the bar to be tested is supported. The pressure is exerted by means of a hand-wheel, K, turning a large square-threaded screw which works in a large nut supported by two bolts, F F, which pass down to and are secured by large washers and nuts to a heavy oak cross-

beam, G, underneath. The stresses thrown on the bar by the hand-wheel and screw are resisted directly by the platform of the scale, and are registered on the scale-beam M, which is graduated to read to two pounds, but is sensitive to less than half a pound. To insure more accurate

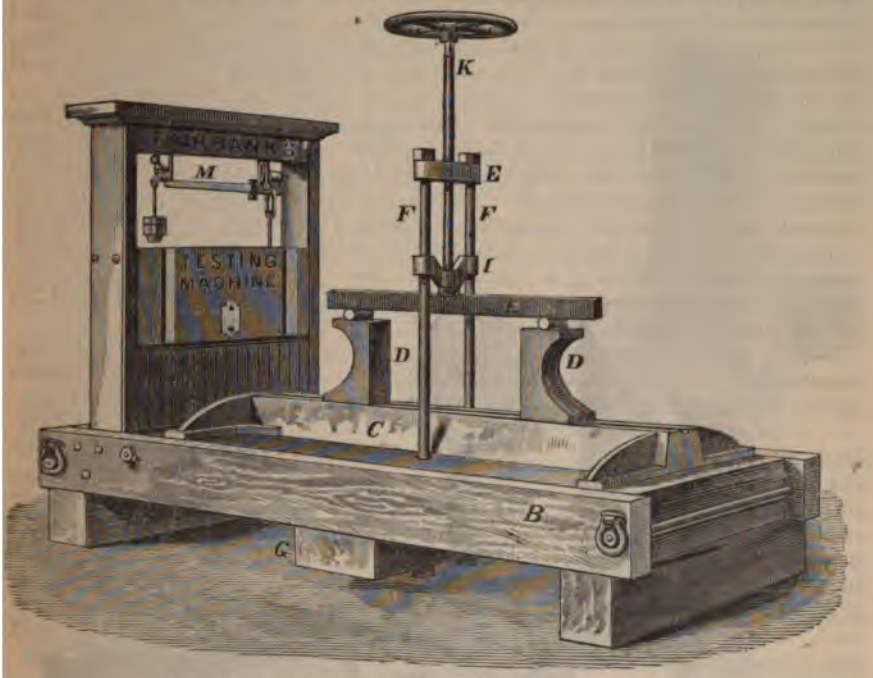

Fig. 12.—Fairbanks' transverse testing-machine.

balancing, a pointer was attached to the end of the scale-beam, which moves across a graduated arc. The pointer was always brought to rest at the middle of the arc in taking the observations. The apparatus has worked very satisfactorily and gives results with much greater rapidity, and with equal, if not greater, correctness than the machines used in testing the first series, in which weights were required to be lifted on and off the bar whenever a set was observed.

In testing ductile metals with this machine, it will be noticed that results are obtained very different from those with dead loads when the bar is allowed to rest under stress for any length of time. In the test by dead loads, when a load is placed on a bar and the deflection is allowed to increase, the load continues to act as long as the test continues. In the test by the pressure-screw and scale-combination, the deflection is maintained constant by the screw, while the decrease of resistancing of the bar is shown by the dropping of the scale-beam, and its balancing by a smaller weight, moving the sliding poise to a lower figure on the beam.

To test a ductile metal by the pressure-screw exactly as with dead loads, it would be necessary to continue turning the hand-wheel just rapidly enough to keep the scale-beam constantly balanced, so that the pressure would remain constant and the deflection increase as in the test under dead loads. With very ductile metals, which show under some loads a decreasing, and under heavier loads a rapidly increasing, rate of

increase of deflection, this would be impracticable. To observe the effect of time in tests of the ductile metals, therefore, the deflection was measured when the scale-beam balanced at a certain figure, and then, as the beam dropped, showing a decrease of resistance of the bar to stress, the poise was pushed back until the beam balanced again, and the figure on

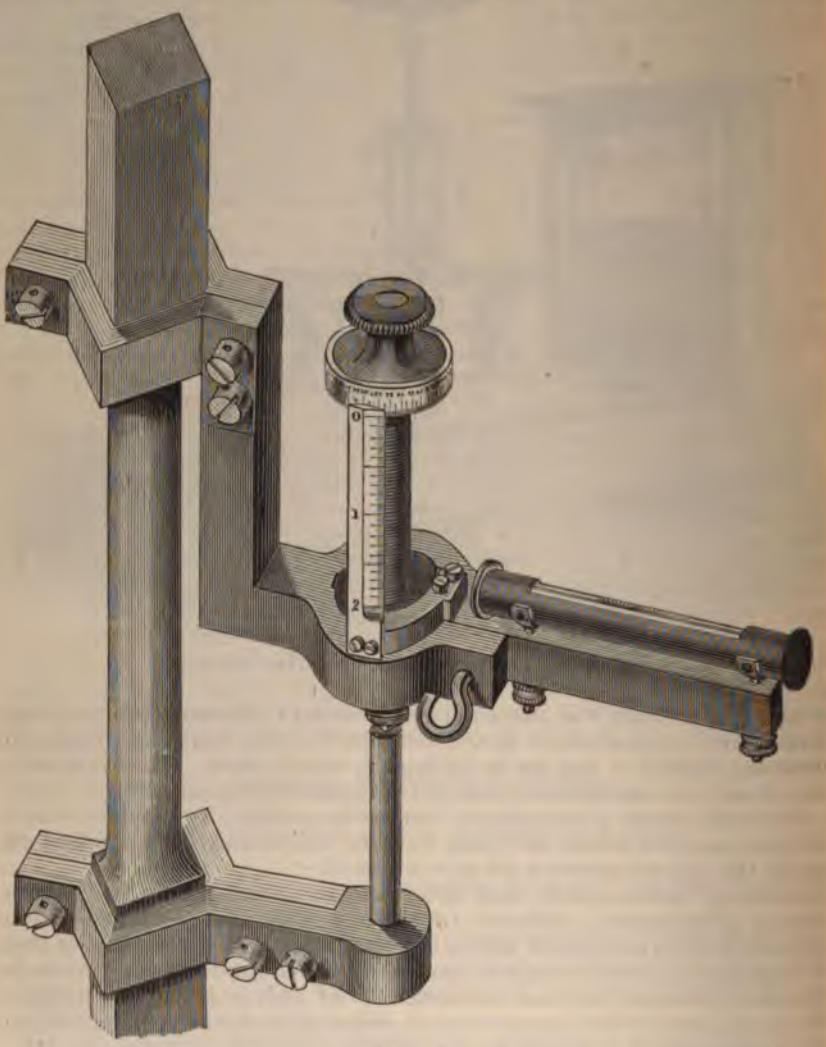

FIG. 13.

the beam recorded and the time noted. As the beam dropped again it was again balanced, and so on as long as it was desired to continue the test.

In the appended tables of the tests of the second series, therefore, it will be observed that when "time tests" are made, instead of noting the increase of deflection with various times of leaving under stress, as in the first series, the decrease of resistance is noted, as measured on the

scale-beam. The decrease of resistance to stress is also frequently noted in these tables by the words "beam sinks," when the beam was observed to drop while taking the reading of the deflection, but when the test was at once continued without stopping for "time tests."* The deflections of the bars tested in this apparatus were measured by an instrument (Fig. 13) designed for the purpose, which consists of a micrometer screw and contact level, similar to the instrument used by the United States Coast Survey for comparing standard measures of length.

The screw has 40 threads to the inch, and the head is divided into 250 parts, so that a turn of the screw through a distance indicated by one division on the scale corresponds to an advance of the screw through its nut of $\frac{1}{10000}$th of an inch. The screw and the nut in which it works are carried by a bronze piece supported by two pivot screws. This piece also carries a very delicate astronomical level. The readings of the head of the screw are taken when the bubble of the level is exactly in the center of its glass, and, when care is taken, the readings are given with accuracy to the $\frac{1}{10000}$th of an inch. The instrument was tested carefully in the Physical Laboratory of the Stevens Institute of Technology, and the pitch of the screw was found to be uniform within the limits of error of the reading, and the level to have the required delicacy of action.

The pitch of the screw, however; has an error which is proportional to its length, amounting to 0.000741 inch in each inch of its length, the inch indicated by the instrument being, accurately, 0.99925 inch.

In using this instrument to measure deflections, in tests by transverse stress, it is mounted on an iron standard which is bolted firmly to the middle of the heavy base-plate of the machine, and placed in such a position that the end of the micrometer screw rests on a flat surface on the upper side of the piece which acts on the middle of the bar to be tested, and through which the pressure is applied. This piece is guided by the rods which sustain the nut in which the large pressure-screw rotates, in such a manner that it can only move in a vertical direction.

A special test was made of the accuracy of the method of measuring deflections, and a slight error was found to arise from the deflection of the bed-plate of the testing-machine. This error was found to amount to 0.0050 inch when the machine was strained to its working limit, viz, 4,000 pounds, and it was also found to be proportional to the stress, or 0.00000125 inch for each pound of stress, which error, if absolute accuracy is desired, should be added to the observed deflections.

In testing the softer metals an error is introduced by the compression of the bar at the point which is touched by the pressure-block and the points which rest on the rollers. The effect of this compression can, in some cases, be seen on the bars after they have been tested. This error seemed to be nearly constant after the application of about a hundred pounds, the pressure-block and rollers appearing to form permanent beds for themselves. It may partially account for the apparently greater increase of deflections for equal increments of load near the beginning of the test than elsewhere near the elastic limit, and therefore for the apparent irregularity in the moduli of elasticity.

Tables are appended giving the records of the test of each bar, and the following table presents a condensed summary of all results:

*See paper by the writer "On the Rate of Set," &c., Appendix.

TABLE VIII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Transverse Stress.

No.	Mean composition by analysis.		Length between supports.	Breadth.	Depth.	Breaking load.	Modulus of rupture. $R=\frac{3Pl}{2bd^2}$	Total deflection.	Limit of elasticity.		First set of 0.01 inch.		Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$			Remarks.
	Copper.	Tin.	l	b	d	P		Δ	Load P_1	Corresponding value of $R_1=\frac{3lP_1}{2bd^2}$	Load P_2	Corresponding value of $R_2=\frac{3lP_1}{2bd^2}$	P	Δ	E	
			Inches.	*Inches.*	*Inches.*	*Pounds.*		*Inches.*	*Lbs.*		*Lbs.*					
31	99.09	0.87	22	0.956	0.977	360	13,014	0.1568	200	7,230	200	7,230	200	0.0674	8,860,059	Bar defective.
32	94.11	5.43	22	0.956	0.982	1,080	38,659	8. +	400	14,317	400	14,317	400–200	0.0433	13,581,817	Bent.
33	88.41	11.59	22	0.973	0.977	1,700	60,403	4. +	600	21,319	600	21,319	600–120	0.1129	12,472,655	
34	82.70	17.34	22	0.950	0.970	1,840	67,930	0.6125	1,040	38,395	1,040	38,395	840	0.1702	15,152,664	
35	77.56	22.25	22	0.965	0.968	820	29,926	0.1606	820	29,926	820	29,926	800	0.1606	15,149,535	
36	72.89	26.85	22	0.998	1.004	290	9,512	0.0475	290	9,512	290	9,512	240	0.0386	16,387,041	
37	67.87	32.10	22	0.964	0.987	270	9,477	0.0520	270	9,477	270	9,477	270	0.0520	14,896,691	
38	62.42	37.48	9	0.985	0.995	210	2,907	0.0185	210	2,907	210	2,907	200–80	0.006	3,156,575	Modulus of elasticity doubtful.
39	57.88	42.05	17	1.000	0.985	142	3,732	0.0210	142	3,732	142	3,732	102	0.0150	8,739,548	Do.
40	53.46	46.55	9	1.015	1.000	150	1,995	0.0080	150	1,995	150	1,995	141–81	0.0025	4,306,523	Do.
41	47.27	52.72	15	0.962	0.980	230	5,601	0.0186	230	5,601	230	5,601	220	0.0186	11,022,256	
42	43.99	55.91	18	0.995	0.995	222	6,084	0.0357	222	6,084	222	6,084	142	0.0215	9,824,640	
43	37.10	62.90	22	0.970	0.990	100	3,971	0.0799	100	3,971	.....	.....	40	0.0106	10,672,961	
44	30.76	69.19	22	0.985	0.990	210	7,178	0.1122	100	3,418	.....	.....	80	0.0319	6,984,987	
45	26.63	73.17	22	0.978	0.985	320	11,128	0.2204	140	4,864	160	5,564	40	0.0146	7,803,107	
46	22.10	77.58	22	0.980	0.992	400	13,687	0.4051	120	4,106	.....	.....	60	0.0197	8,474,849	
47	16.70	83.23	22	0.996	0.983	300	10,288	0.5332	80	2,744	100	3,429	40	0.0153	7,356,258	
48	11.69	88.27	22	0.985	0.990	300	10,254	1.0760	60	2,051	100	3,418	40	0.0141	7,901,458	
49	6.05	93.77	22	0.990	0.995	280	9,764	3.67 +	60	2,020	100	3,367	40	0.0137	7,969,719	Bent.
50	2.11	97.68	22	0.991	0.997	250	8,375	3.93 +	60	2,010	.....	.....	.....	.....	6,692,585	Do.

NOTES ON THE TESTS BY TRANSVERSE STRESS.

Comparing the results given in the above table with those of the transverse tests of the first series, given in Table II, page 302, it will be seen that there is a very close resemblance, indicating that there is a definite law connecting the strength with the composition of the copper and tin alloys, and that a regular curve can be laid down expressing this law.

It will be seen that in the second series the maximum strength was shown by No. 34 (82.72 copper, 17.33 tin), while in the first series it was exhibited by No. 7 (80.95 copper, 18.84 tin), which differed but little from that composition. In both series there is a regular but rapid decrease of strength to alloys No. 13 (56.70 copper, 43.17 tin) of the first series, and No. 40 (53.46 copper, 46.54 tin) of the second series. From these compositions to the end of each series all of the bars possess but little strength, but there is a slow and somewhat irregular increase of strength from No. 13 and No. 40 to No. 21 (23.35 copper, 76.29 tin) in the first series, and No. 46 (21.60 copper, 77.58 tin) in the second series, which bars are what has been called the "second maximum" points in the curves of each series. Their resistances then gradually decrease to the end of each series, the bars at the end giving the "second minimum" points in each curve. The irregularity in strength in the latter part of the first series does not occur in the second series, since the latter was tested with more uniformity as to time than the former.

The results of these tests do not seem to corroborate the theory given by some writers, that peculiar properties are possessed by the alloys which are compounded of simple multiples of their atomic weights or chemical equivalents, and that these properties are lost as the compositions vary more or less from this definite constitution. It does appear that a certain percentage composition gives a maximum strength and another certain percentage a minimum, but neither of these compositions is represented by simple multiples of the atomic weights.

Besides, there appears to be a perfectly regular law of decrease from the maximum to minimum strength which does not seem to have any relation to the atomic proportions, but only to the percentage composition.

Referring to the appended tables, giving the record of the test of each bar, and the plate of plotted curves which accompanies them, the following observations may be made concerning these tests.

Bar No. 31 (99.09 copper, 0.87 tin).—This bar proved upon test to be a bad casting, and apparently had a crack in the middle which was not discovered till after 360 pounds pressure had been placed on it. The limit of elasticity appeared to be reached at about 200 pounds, and a set of .01 inch was observed at the same point, both of which indicated the defective strength before rupture. The modulus of elasticity also was much less than those of other bars of nearly the same composition. After breaking, the fracture showed the metal to be full of blow-holes and it had a partially oxidized appearance. As bar No. 2 (97.89 copper, 2.11 tin) of the first series was also defective, it is indicated that faulty castings are very likely to occur with alloys containing less than 3 per cent. of tin. It is possible, however, that sound bars may be made if the metal is poured at the proper heat and cooled at the proper rate. As this bar was defective, it is omitted from the plotted curves (Plate I).

Bar No. 32 (94.10 copper, 5.43 tin).—This proved to be a good bar, and bent without breaking at a load of 1,080 pounds. From the plotted curves of stresses and deflections (Plate XVII) it appears that the limit of elasticity was reached at about 600 pounds.

A set of 0.0145 inch took place at 400 pounds. At 440 pounds the scale-beam was observed to drop while taking the deflection, immediately after it had been balanced, showing a decrease of resistance to constant deflection, which has been commented upon in describing the action of the machine (page 347). This also occurred at every load beyond 440 pounds, although it is not noted in the table. It is to be understood that in all tests in which a decrease of resistance to stress is noted, that decrease also took place at every load succeeding that at which it is first observed, to the end of the test.

A "time test" was made at 600 pounds, showing a decrease of resistance in 2 minutes to 586 pounds, and in 1 hour 48 minutes to 562 pounds.

Bar No. 33 (88.40 copper, 11.59 tin).—This bar proved much stronger than No. 32, breaking at a load of 1,700 pounds, after a deflection of about 4 inches. A set of 0.0112 inch was observed at 600 pounds, and the limit of elasticity is taken at this point. At 720 pounds the bar showed a decrease of resistance, the scale-beam slowly sinking below its middle position. This bar differed but little in composition from No. 6 (87.15 copper, 12.73 tin) of the first series, which was found to be defective by reason of liquation, and it confirms the indication mentioned under the transverse test of No. 6, that the liquation was not caused by the particular mixture or composition, but by some peculiarity in casting or cooling. The fracture of this bar was in color a light grayish-yellow, slightly darker in the center, and of an earthy appearance, entirely devoid of luster; a few very small blow-holes were seen around the edges of the fracture. It resembled somewhat the more homogeneous fractures of bar No. 5 (90.27 copper, 9.58 tin). Its shape was trapezoidal, a characteristic of all fractures by transverse stress of metals possessing considerable ductility. The measurement of this fracture showed the breadth at the top to be 1.003 inches and at the bottom 0.937 inch. The depth was 0.972 inch. The original section of the bar was rectangular, breadth 0.973 inch, and depth 0.977 inch.

Bar No. 34 (82.72 copper, 17.23 tin).—This bar was the strongest of the series, and also stronger than any bar in the first series. It broke at 1840 pounds, after a deflection of 0.6125 inch. A set of 0.0098 inch was observed at 1,000 pounds, and the limit of elasticity was reached at 1,040 pounds.

In breaking, the bar gave out a ringing sound, and the two halves flew out from under the pressure-screw, and were found on the platform about four feet apart. The fracture was of a pinkish-gray color, very fine, granular, and homogeneous, except a spot in the center which appeared to be a mottled mixture of the pinkish-gray with a dull, earthy, yellowish-gray. There were no signs of a decrease of resistance throughout the test during the times necessary to take readings of deflections (from 30 seconds to 1 minute each). The fracture took place just as the last reading of deflection was taken, and about 30 seconds after the beam was balanced at 1,840 pounds, the beam remaining balanced until the instant of rupture. The appearance of the fracture and the behavior under stress were very similar to those of bar No. 7 (80.95 copper, 18.84 tin), which broke at 1,750 pounds, and was the strongest bar of the first series. It appears that the maximum strength is associated with a peculiar color, a reddish or pinkish gray, which marks the change from the ductile alloys to the brittle ones, and occurs between the percentages of tin which give a silver-white alloy in which no trace of copper could be detected by the eye, and the reddish-yellow to yellowish-gray alloys like No. 6 (lower end of bar) and No. 33.

The tests of No. 7 and No. 34 are not sufficient of themselves to de-

ermine with accuracy the composition which gives the maximum rength of all the alloys of copper and tin; but from the plotted curves the tests of both series it appears evident that it lies between 82.5 and 5 per cent. copper.

Bar No 35 (77.56 copper, 22.25 tin).—This bar had less than half the rength of No. 34, breaking at 840 pounds after a deflection of 0.1606 ch, thus again exhibiting the result shown in the test of the first series, e very rapid decrease of strength between 80 and 75 per cent. of cop- r. In all its qualities it closely resembled No. 8 (76.63 copper, 23.24) of the first series. The color of the fracture was the same, a very ght pinkish gray, with a very fine granular structure, but showing ght radiated lines of cooling which were not present in the fractured rface of No. 8. No set amounting to 0.01 inch could be detected dur- g the test, and the limit of elasticity was not reached before fracture; e bar, therefore, possessed all the qualities of the brittle alloys, com- ned with a considerable degree of strength.

Bar No. 36 (72.89 copper, 26.85 tin.)—This bar also illustrates the sud- en decrease of strength after passing the maximum, breaking at 290 ounds, after a deflection of 0.0475 inch. The limit of elasticity was not eached before fracture, and no set amounting to 0.01 inch was found. he fracture was of a brilliant silver-white color, with a very faint tinge f pink. It had a curved shape, like those of No. 9 (69.84 copper, 29.88 in) and No. 10 (68.58 copper 31.26 tin) in the first series, and, like them, howed a laminated or prismatic structure. In all respects the bar re- embled No. 9 and No. 10, except in the pinkish shade of color which was absent in both of the latter. It appears, therefore, that the change in color from light pinkish gray to silver-white takes place between the compositions containing 76.63 and 72.89 per cent. of copper, and that the change is gradual between these limits.

Bar No. 37 (67.87 copper, 32.09 tin).—This bar was a little weaker than No. 35, breaking at 270 pounds, after a deflection of 0.0520 inch. Like all of the brittle bars it had no elastic limit before fracture, and no set amounting to 0.01 inch. The fracture was precisely similar to that of No. 10 (68.58 copper 31.26 tin) of the first series.

Bar No. 38 (62.42 copper, 37.48 tin).—The piece of this bar which was tested by transverse stress was only 9 inches in length between supports, the bar having broken in the emery-wheel planer as already mentioned on page 346. This piece broke at 210 pounds giving a modulus of rupture, $R = \frac{3Pl}{2bd^2}$, of 2907 pounds, or less than one-third that of No. 37. The deflection with 200 pounds stress was 0.0185 inch. This de- flection appears to give a very low modulus of elasticity, only 2,000,000 pounds, or 3,000,000 if the modulus is taken between the loads of 80 and 200 pounds to eliminate the probably erroneous readings of deflection at the beginning of the test. The formula by means of which the mod- ulus of elasticity is calculated, $E = \frac{Pl^3}{4 \triangle bd^3}$, however, is not exact for short specimens as it does not take into account the effect of shearing stress, as has been observed on page 303.

The figures of moduli of elasticity in all the bars of this series which have less than the standard length of 22 inches between supports, are therefore probably much too small. Moreover, the effects of all the er- rors in the test, those of observation, those due to compression of the points of the bar touched by the supports, and by the pressure-block, and those due to the unevenness of the bearing, will all be increased and will tend to increase the apparent deflection.

The fact that liquation occurred in this bar was noted on page 346. The fracture by transverse stress also exhibited liquation as it differed in appearance from both of the accidental fractures. It was of a dark gray color and stony structure, with no radiated lines or laminæ, and was not homogeneous, parts being brilliant and parts dull.

Bar No. 39 (57.87 copper, 42.05 tin).—The length of the bar when tested was 17 inches. It broke at 142 pounds after a deflection of 0.021 inch, giving a modulus of rupture somewhat higher than No. 38. The apparent modulus of elasticity is much higher than that of No. 38. The fracture was of a light-gray color and stony structure, showing some radiated lines.

Bar No. 40 (53.46 copper, 46.54 tin).—This bar was only 9 inches long between supports, and it proved to be the weakest of the series, breaking at 150 pounds with a deflection of only 0.008 inch, giving a modulus of rupture of 1,995 pounds. The apparent modulus of elasticity is very low, as in the cases of the other short bars. The color of the fracture was light gray and it had a radiated lamellar structure. It was not distinguishable from the fracture of No. 39. It was also similar in appearance to No. 13 (56.70 copper, 43.17 tin), which was the weakest bar in the first series.

Bar No. 41 (47.27 copper, 52.72 tin).—The length of this bar was 15 inches between the supports. It was much stronger than No. 40, breaking at 230 pounds after a deflection of 0.0186 inch, giving a modulus of rupture of 5,601 pounds. From the position of this test in the curve strengths of the series, it is seen that it also indicates a law of gradual increase of strength from the bar of minimum strength, No. 40, to the bar of "second maximum" strength, No. 46 (21.60 copper, 77.58 tin), which was also shown in the test of the first series. The fracture was very much like that of No. 40.

Bar No. 42 (43.99 copper, 55.91 tin).—This bar was 18 inches in length between the supports. It was a little stronger than No. 41, breaking at 222 pounds, giving a modulus of rupture of 6,084 pounds after a deflection of 0.0357 inch. The bar did not break in the middle, as is nearly always the case in transverse tests, but 4 inches from the middle, or 5 inches from the upper or A end of the bar. The longer piece (marked E–c) remaining after the test was then also tested, being 13 inches in length between the supports. It gave a result slightly higher than the original bar, breaking at 362 pounds, giving a modulus of rupture of 6,605 pounds after a deflection of 0.031 inch. The apparent modulus of elasticity given by this test is only about half of that given by the original bar, which only serves to confirm the statement already made as to the unreliability of the moduli of elasticity derived from tests of very short bars. The fractures were similar in color to those of No. 41, but showed a compact stony, instead of a radiated and laminated appearance. The accidental fracture near the bottom of the original bar, however, did show the radiated structure, as did also bar No. 43.

The analyses of turnings from two different parts of this bar showed that a large amount of liquation had occurred, the turnings from the lower part of the bar containing more than 22 per cent. less copper than those from the upper. This is sufficient to account for the breaking in a section other than the middle, and for the difference in appearance of the fractures.

Bar No. 43 (37.10 copper, 62.90 tin).—This bar was of the standard length, 22 inches, and shows an increase of strength over No. 42, breaking at 200 pounds, or at a modulus of rupture of 6,942 pounds after a deflection of 0.0799 inch. A set of 0.0202 inch was observed just before

rupture took place, thus showing more ductility than either of the five previous bars. From this point to the end of the series the ductility increases. It will be observed that in this, and in all of the more ductile bars containing large percentages of tin, the moduli of elasticity appear to decrease from the beginning of the test, while in the brittle bars they either remained nearly constant or showed a slight increase. In the latter the limits of elasticity, or points at which the ratio of distortion to stress increases are not reached before fracture occurs. In the former, they occur very near the beginning of the tests, but its exact place is difficult to determine. On the plate of curves of deflections this is plainly seen, as the curves of these ductile bars show a curvature concave to the axis of abscissas almost from the beginning of the test. The limit of elasticity is usually taken as the point at which the curve begins suddenly to become concave toward the axis, but in the ductile bars in which this point of change is not plainly marked, it is assumed to be that point at which the *greatest* change of curvature seems to take place, or a little before the curve assumes a nearly horizontal direction. By inspection of the curve of No. 43 its limit of elasticity is determined to be pounds. When 100 pounds had been placed on the bar, a decrease of resistance to stress was noted, the scale-beam dropping while the reading was being taken, as was observed in the cases of bars No. 31 to No. 34. This was also observed in all bars from No. 43 to the end of the series.

The fracture was of a light-gray color, and showed very large prismatic crystallization similar to that of No. 19 (34.22 copper, 65.80 tin) of the first series.*

Bar No. 44 (30.76 copper, 69.19 tin). This bar also showed the increasing strength and increasing ductility of this part of the series as the percentage of tin increases. It broke at 210 pounds after a deflection of 0.1122 inch. A set of 0.0325 inch was observed at 200 pounds. From the curves of deflections (Plate XVII) the limit of elasticity appears to have been reached at 100 pounds, at which load the bar first exhibited a decrease of resistance to constant deflection. The appearance of the fracture was precisely like that of No. 43.

Bar No. 45 (26.62 copper, 73.18 tin). This bar was considerably stronger and more ductile than No. 44, breaking at 320 pounds after a deflection of 0.2204 inch. A set of 0.0145 inch was observed at 160 pounds, and from the curve the limit of elasticity appears to have been reached at 160 pounds. The decrease of resistance under constant deflection was first found at 80 pounds, and a "time test" of this decrease was made at 160 pounds. As shown in the table, after the beam had been balanced for the second time at 160 pounds, the resistance decreased in 1 minute to 154 pounds, in 3 minutes to 150 pounds, in 44 hours to 104 pounds, and in 69 hours to 100 pounds, showing a gradually decreasing rate of the decrease. The fracture was similar in color to those of No. 43 and No. 44, but the crystals were much smaller, and had more of a granular appearance.

Bar No. 46 (22.10 copper, 77.58 tin).—This bar gave the "second maximum" point of strength in the curve of the series, breaking at 400 pounds after a deflection of 0.4051 inch. It closely resembled in all its qualities the bar which gave the "second maximum" in the first series, No. 21 (23.35 copper, 76.29 tin), but did not have a cavity throughout its length such as was seen in the latter. A set of 0.0047 inch was observed at 100 pounds, and one of 0.0357 inch at 200 pounds. The decrease of

* See description of fracture of No. 19 by Professor Leeds, page 312.

resistance with time was first observed at 100 pounds; from the curve of deflections the limit of elasticity is seen to be at pounds. The fracture was similar to that of No. 45.

Bar No. 47 (16.70 copper, 83.23 tin).—This bar proved to be a little weaker than No. 46, thus confirming the law of decrease of strength from the second maximum to the end of the series. It broke at 300 pounds after a deflection of 0.5332 inch. A set of 0.0092 inch was observed at 100 pounds, and from the curve of deflections the limit of elasticity was apparently reached at about 100 pounds. The fractured surface was similar to that of No. 46.

The phenomenon of *decrease of set with time* was observed for the first time with this bar; the table of the record of test giving the full record of all the observations made. On relieving the bar of all pressure except that due its own weight, and except a very slight pressure (a few ounces) to insure that the pressure-block actually touched the bar and was not raised from it, the scale-beam balanced at 5 pounds, and the reading of the set was made. While reading the set the scale-beam was observed to rise, indicating *increase* of resistance to deflection, as it had similarly been observed to drop when resistance to stress took place. A number of observations of this increase of resistance to the permanent deflection were made, and also of the decrease of set, as measured by running back the pressure-screw till the scale-beam again balanced at 5 pounds, and taking additional readings. The result of these observations, which are all given in the table, showed that in one observation of 39 minutes the resistance of the bar, as measured by the scale-beam, increased 18 pounds, and that in 2 hours 20 minutes the set decreased the amount of 0.0239 inch.

This fact of the decrease of set with time has since been confirmed by a large number of tests made on the same machine, and it has also been observed by other experimenters. It indicates that what has been hitherto called the "permanent set" of metals is in reality not entirely permanent, but is partially, at least, temporary.*

Bar No. 48 (11.68 copper, 88.25 tin).—The result of the test of this bar was almost precisely like that of No. 47, but it showed considerably greater ductility. It broke at 300 pounds, after a deflection of 1.0760 inches. A set of 0.0120 inch was observed at 100 pounds. The limit of elasticity is taken at 100 pounds. The decrease of resistance to stress was first noted at 80 pounds. The phenomenon of decrease of set with time was also observed with this bar, a test of 20 minutes' duration showing a decrease of set of 0.0234 inch. The fracture was of a light-gray color with a rough granular structure.

Bar No. 49 (6.05 copper 93.77, tin).—This bar was weaker and much more ductile than No. 48, bending to a deflection of 3.67 inches without breaking at a load of 290 pounds. A set of 0.0128 inch was observed at 100 pounds, and the limit of elasticity seems to be reached at about this point. The decrease of resistance to stress was first observed at 80 pounds. No tests were made of the decrease of set with time.

Bar No. 50 (2.11 copper, 97.68 tin.)—This bar was still weaker than No. 49, bending to a deflection of 3.93 inches, without breaking at a load of 250 pounds. A set of 0.0164 inch was observed at 100 pounds, and the limit of elasticity seems to be reached at about 60 pounds. The decrease of resistance with time was first noticed at 60 pounds. At 210 pounds the beam was caused to balance twice after it had dropped, the deflection at the same time being increased from 0.85 to 1.08 inches.

* See paper by the writer, &c.

This indicated that a much less load than 250 pounds would have caused the final recorded deflection of 3.93 inches, if sufficient time had been given to it.

It will be observed, on comparing the results of the tests of No. 49 and No. 50 with those of bars of nearly similar composition in the first series, that the former gave much higher results than the latter. This is due entirely to the method of test, or rather to the time taken by the different methods. In the tests of the ductile bars of the first series, by dead loads, as already stated, the load acted constantly to produce an increased deflection while the reading was being taken, and thus a much less load was required to produce a certain deflection than would have been required if the test had been made more rapidly. In the tests of the second series all the conditions of a rapid test were fulfilled, since the deflection was not increased while the reading was being taken, and also since the actual time occupied by the test was very much less in consequence of the greater convenience of handling the apparatus.

TESTS BY TENSILE STRESS.

Second series. Alloys of Copper and Tin.

The bars of the second series, after having been tested by transverse stress, as above described, were shaped by being turned in a lathe into pieces for test by tensile stress of the same shape as those of the first series, with the cylindrical portion of the test-piece 5 inches in length and 0.798 inch in diameter, or $\frac{1}{2}$ square inch sectional area. The bars, which were too brittle to be turned, were tested in their original rectangular section.

The tests were made on the testing-machine (Fig. 6, page 314), described under the tests of the first series.

The elongations were measured by means of the contact-level and micrometer-screw (Fig. 13, page 348), which was used in measuring the deflections in the transverse tests, and which has already been described. In adapting it to tensile tests, the bronze piece containing the two pivot-screws which support the piece carrying the level and nut was firmly clamped by a screw to the rectangular head of the test-specimen just above the cylindrical portion.

At the bottom of the specimen was clamped a similar bronze piece, which carried a small steel cylinder, with a flat upper surface, which the end of the micrometer-screw was brought to touch, and upon which it rested, being free to move about the pivot-screws during the test. When the test-piece, with the measuring-apparatus clamped to it, was placed in the grips of the testing-machine it was brought into a vertical position, and the micrometer-screw was turned in its nut until the bubble of the level was in its middle position. As the test proceeded and the piece elongated, the distance between the two pieces of the measuring-apparatus increased exactly to the extent of the elongation, and the level shifted, requiring the micrometer-screw to be advanced an amount equal to that of the elongation to bring the bubble again to its original position.

The apparatus was found to give good results, except at the beginning of the test, when the piece appeared to take a very slight curvature, the effect of which was at times to cause the apparent elongation to be greater or less than the true elongation.

The curvature or bending of the test-specimen may be produced by either of several causes, or by a combination of them all. These are

chiefly the existence of a blow-hole, or any want of homogeneity in one side of the test-specimen, the fact of the heads of the test-specimen not being accurately symmetrical with the cylindrical portion, or the side strain brought by the testing-machine by reason of the line of stress not being accurately in line with the axis of the test-specimen.

These errors appear to exist only in that part of the test which is below the elastic limit of the specimen, as after that point the stress pulls the piece into the line, which it retains till the end of the test. The bending is so slight usually that it has not been detected, so far as the writer is aware, by any other means of measurement than the one herein described, which magnifies the extensions considerably.

Because of these errors, the figures given in the tables for elongations near the beginning of the test before they amount to 0.01 inch are in many cases not reliable. Where the elongations are greater than this amount, the figures are considered very accurate, with perhaps a slight error, which is constant throughout the test. For the same reason, the recorded figures of elongations cannot be relied upon to give correct moduli of elasticity by tensile stress, which might have been done if the error due to the bending of the specimen had been entirely eliminated. With the exception of these errors, the measurements are believed to be much more nearly correct than those of the first series, which were made simply by means of a pair of finely-pointed dividers and readings on a scale to $\frac{1}{100}$th of an inch.

The results of the tests by tensile stress of the second series have been entirely confirmatory of those of the first series and of the tests by transverse stress of both series.

The appended tables contain the complete records of the tests of each bar. The following table presents a condensed summary of results:

TABLE IX.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Tensile Stress.

Number.	Composition by analysis.		Diameter of—		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds*		
31 A	99.40	0.52	0.798	0.770	0.0170	13,000	13,958	7,000	Defective bar.
31 B	98.79	1.22	0.798	0.770	0.0155	15,250	16,374	6,000	Do.
Mean	99.09	0.87	.....	0.770	0.0163	14,125	15,166	6,500	
32 A	93.98	5.47	0.798	0.690+	0.0779	28,500	35,922	14,000	
32 B	94.23	5.39	0.798	0.720+	0.0706	27,300	32,844	14,000	
Mean	94.11	5.43	.....	0.705	0.0743	27,900	34,383	14,000	
33 A	88.35	11.61	0.798	0.776	0.0226	29,000	30,658	20,000	
33 B	88.46	11.57	0.798	0.770	0.0485	33,200	35,648	22,000	
Mean	88.41	11.59	.....	0.773	0.0356	31,100	33,153	21,000	
34 A	82.72	17.33	0.798	0.795	0.0071	40,200	40,492	.....	
34 B	82.69	17.34	0.798	0.798	0.0071	32,200	32,200	.....	
Mean	82.70	17.34	.....	0.797	0.0071	36,200	36,346	.....	
35 A	77.41	22.27	0.798	0.798	0.0042	23,600	23,600	.....	
35 B	77.71	22.23	0.798	0.798	0.0066	25,700	25,700	.....	
Mean	77.56	22.25	.....	.....	0.0054	24,650	24,650	.....	
36 A	72.85	26.80	.....	.....	.....	6,500	6,500	.....	Rectangular section, 0.998″×1.002″.
36 B	72.94	26.90	.....	.....	.....	6,485	6,485	.....	Do ... 1.010″×1.000″.
Mean	72.89	26.85	.....	.....	.....	6,493	6,493	.....	

TABLE IX.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Tensile Stress—Continued.

ber.	Composition by analysis.		Diameter of—		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit—pounds per square inch.	Remarks.
	Copper.	Tin.	Original section.	Fractured section.		Original section.	Fractured section.		
			Inches.	*Inches.*		*Pounds.*	*Pounds*		
.....	67.66	32.22	.....	.....	.....	1,644	1,644	.....	Rectangular section, 0.975″×0.990″.
.....	68.08	31.98	.....	.....	.....	3,408	3,408	.....	Do ...0.982″×0.985″.
an ..	67.87	32.10	.....	.....	.....	2,536	2,536	.....	
.....	67.59	32.32	.....	.....	.....	2,335	2,335	.....	Do ...0.980″×0.992″.
.....	63.69	36.27	.....	.....	.....	.....	.....	.....	
.....	55.90	43.85	.....	.....	.....	787	787	.....	Do ...0.983″×0.990″.
an ..	62.42	37.48	.....	.....	.....	1,561	1,561	.....	
.....	64.21	35.56	.....	.....	.....	1,200	1,200	.....	Do ...0.982″×0.990″.
.....	51.54	48.54	.....	.....	.....	1,553	1,553	.....	Do ...0.988″×0.997″.
an ..	57.88	42.05	.....	.....	.....	1,377	1,377	.....	
.....	47.10	52.86	.....	.....	.....	1,919	1,919	.....	Do ...0.968″×0.985″.
.....	47.43	52.59	.....	.....	.....	2,894	2,894	.....	Do ...0.960″×0.990″.
an ..	47.27	52.72	.....	.....	.....	2,407	2,407	.....	
.....	55.21	44.80	.....	.....	.....	2,273	2,273	.....	Do .. 0.992″×1.004″.
.....	32.77	67.02	.....	.....	.....	1,924	1,924	.....	Do ...0.995″×0.987″.
an ..	43.99	55.91	.....	.....	.....	2,098	2,098	.....	
.....	37.62	62.36	0.798	0.798	.....	2,800	2,800	.....	
.....	36.58	63.44	0.798	0.798	.....	2,000	2,000	.....	
an ..	37.10	62.90	.....	.....	.....	2,400	2,400	.....	
.....	33.86	66.01	0.798	0.798	.....	1,592	1,592	.....	
.....	27.66	72.37	0.798	0.798	.....	3,052	3,052	.....	
an ..	30.76	69.19	.....	.....	.....	2,322	2,322	.....	
.....	26.64	73.15	0.798	0.798	.....	3,360	3,360	.....	
.....	26.61	73.20	0.798	0.798	.....	5,400	5,400	.....	
an ..	26.63	73.17	.....	.....	.....	4,380	4,380	.....	
.....	22.09	77.62	0.798	.....	.....	4,200	4,200	.....	
.....	22.11	77.54	0.798	0.796	0.0043	5,800	5,827	.....	
an ..	22.10	77.58	.....	.....	0.0022	5,000	5,014	.....	
.....	16.74	83.11	.....	.....	.....	.....	.....	.....	
.....	16.66	83.36	0.798	0.797	.....	2,816	2,822	.....	
an ..	16.70	83.23	.....	.....	.....	.....	.....	.....	
.....	11.67	88.25	0.798	0.795	.....	3,416	3,440	.....	
.....	11.70	88.24	0.798	0.795	0.0110	4,180	4,210	2,000	
an ..	11.69	88.24	.....	0.795	0.0055	3,798	3,825	.....	
....	6.07	93.75	0.798	0.710	0.1742	6,192	7,981	3,200	Tenacity per square inch fractured section doubtful.
.....	6.03	93.79	0.798	0.680	0.2302	6,000	8,260	2,000	Do.
an ..	6.05	93.77	.....	0.695	0.2022	6,096	8,121	2,600	
.....	2.18	97.60	0.798	0.545	0.4100	5,600	12,002	1,200	Do.
.....	2.03	97.77	0.798	0.530	0.3900	5,600	12,691	1,200	Do.
ean ..	2.11	97.68	.....	0.538	0.4000	5,600	12,397	1,200	

NOTES ON THE TESTS BY TENSILE STRESS.

No. 31.—As was shown by the transverse test of this bar, it was a de-tive casting. The tensile tests also gave very low results, and they e rejected from the tables and from the curves of average results of e series (Plates II, VII, VIII). The turned surfaces of the test-ces from this bar revealed a liquation or separation of the metals o two alloys, or possibly a heterogeneous mixture of unalloyed cop-r, with an alloy containing a considerable amount of tin. The turned

surface was in general of a copper-red color, not at all distinguishable from the appearance of pure copper; but there were small yellow spots irregularly distributed over the whole surface. The fractures showed a similar appearance, the larger portion being of a copper color, and the remainder consisting of a few yellowish-gray spots. The turned surfaces and the fractured surfaces also contained several small blow-holes.

No. 32 (94.40 copper, 5.43 tin).—The two pieces from this bar gave very similar results, which show a fair degree of strength for metal of its composition cast in the ordinary manner. The fractures were of a yellowish-red color, and earthy structure, and contained several very small blow-holes.

No. 33 (88.40 copper, 11.59 tin).—The two test-pieces showed a somewhat greater strength than those of No. 32. The fractured surfaces were of a reddish-yellow color, and earthy structure, and contained several very small blow-holes. These were more numerous in No. 32 A than in No. 32 B, which may account for the greater strength of the latter.

No. 34 (82.72 copper, 17.33 tin).—The average of the two tests of this bar showed considerably greater strength than No. 33, but the piece from the bottom of the bar was much weaker than that from the top, and slightly weaker than the bottom piece of No. 32. This does not appear to have been due to liquation, as the analyses of the turnings from the two tension-pieces give almost precisely similar results, which differ but little from the original mixture. It may possibly have been due to a more imperfect mixture of the metals in one portion of the bar than in another, causing a want of homogeneity, which is partly indicated by the appearance of the fractured surfaces. The fracture of No. 34 A was chiefly of a pinkish-gray color, similar to those of No. 7 and No. 8 of the first series. The structure was very finely granular, with an indistinct appearance of radiated lines of cooling. In the center was a spot about ¼ inch in diameter, which had a mottled mixture of the pinkish-gray and a yellowish-gray color. The fracture of No. 34 B was similar to that of No. 34 A, the larger part of the surface being of a pinkish-gray color and fine granular structure, but without any radiated lines of cooling. It also contained a spot in the center, which in this case was not mottled, but was of one color, a reddish or brownish gray.

The average tensile strength of the two pieces from this bar is higher than that given by any other bar in this series, and is also higher than that of any bar in the first series, agreeing in this respect with the results of the transverse tests.

No. 35 (77.56 copper, 22.25 tin).—The strength of this bar, as shown by the tensile tests, was much less than that of No. 34. The fractures have the same pinkish-gray color that was seen in No. 34, but a shade lighter. The structure shows an appearance of radiated laminæ, very close and compact. It is very similar to that of No. 9 (69.84 copper, 29.89 tin) of the first series, but the color is entirely different, the latter being nearly a silver white. The fractures of both pieces of No. 35 were precisely alike, and a very small blow-hole was found in the center of each.

No. 36 (72.89 copper, 26.85 tin).—The tensile tests of this bar gave results agreeing precisely with those of the transverse test, showing great brittleness and lack of strength. The fractures were similar to that obtained by transverse test, being nearly silver white in color, with a faint pinkish tinge, and a smooth radiated structure.

Bars No. 36 to No. 42 (43.99 copper, 55.91 tin) inclusive, were all tested with their original rectangular section unaltered, as they were too brittle to be turned in the lathe without danger of breaking. All of these bars gave much trouble in setting in the tensile-machine, their

brittleness and hardness being so great that the grips of the machine would not firmly hold them. Most of them broke in the grips, and the figures representing their strengths are therefore in many cases perhaps too low. Several tests were generally made of each of the brittle pieces, and the maximum result is considered to be the one most nearly correct.

No. 37 (67.87 copper, 32.09 tin).—Both tension pieces were much weaker than those of No. 36. The fractures were similar, but the color was silver white, entirely free from any pinkish shade.

No. 38 (62.42 copper, 37.48 tin).—The two test-pieces from this bar showed considerable difference in structure, due to liquation, which has already been noticed on page 346. The fracture of No. 38 A was exactly like those of the two pieces of No. 37, but that of No. 39 was of a dark-gray color and stony structure, similar to that of No. 12 (62.31 copper, 37.35 tin) of the first series, which, as before observed, had the greatest density of the series.

No. 39 (57.87 copper, 42.05 tin).—The average results given by the two test-pieces from this bar show it to be the weakest of the series, and agree in this respect with the result of the test by transverse stress. The fracture of No. 39 A had a stony structure, and the color was a mottled mixture of dark gray and light gray, showing a separation into two alloys. That of No 39 B was light gray throughout and contained radiated laminæ.

No. 40 (53.46 copper, 46.54 tin).—The pieces remaining from the test by transverse stress were too short to be tested by tension.

No. 41 (47.27 copper, 52.72 tin).—Three pieces were tested, giving various results, but all showing great weakness and brittleness. The fractures of all the pieces were alike in appearance, being light gray in color and of stony structure, with indistinctly defined radiated lamination.

No. 42 (43.99 copper, 55.91 tin).—The results of the two tests were similar to those given by No. 41. The fractures were light gray in color, with radiated crystalline structure. The analyses of chips from the two tension pieces of this bar showed a very large amount of liquation to have taken place in the casting. This would scarcely have been suspected from the appearance of the fractures.

No. 43 (37.10 copper, 62.90 tin).—This bar was much softer than the bars from No. 36 to No. 42, and the tension-pieces were turned in the lathe without difficulty. The average of the results shows a very little greater strength than that of No. 42. The fractures were of a light gray, with large radiated prismatic crystals.

No. 44 (30.76 copper, 69.19 tin.)—The two tests gave results which differed considerably, but the average is about the same as those of the two tests of No. 43. The fractured surfaces also showed the same color and structure.

No. 45 (26.62 copper, 73.18 tin).—The results of the two tests differed similarly as those of No. 44, but both tests gave much higher results than the average of the latter, indicating an approach to the point of "second maximum" strength of the series. This was also shown in the tests of this bar by transverse stress. The fractures were of a light-gray color similar to those of Nos. 42 to 44, but were not entirely homogeneous in structure, being coarse granular at the exterior portions of the surface and laminated in the center.

The analyses do not show any difference in composition in the two ends of the bar sufficient to account for any difference in strength or in appearance of the fractures.

No. 46 (22.10 copper, 77.58 tin).—The average of the two tests shows still greater strength than No. 45, but it is not high enough to confirm the point of second maximum strength which was shown by the transverse tests, as it is surpassed by No. 49 and No. 50. The second maximum of both transverse and torsional tests is given by this bar, and bar No. 21 (23.35 copper, 76.29 tin) gave the second maximum in the first series by all three methods of test. The results of the test of No. 46 by tensile stress must therefore be regarded as exceptional, in so far as they give less strengths than No. 49 and No. 50. The curves of the strengths of the series by the different methods of test, moreover, show the tensile test of No. 49 and No. 50 to give higher results than the other methods of test of the same bar. This may probably be accounted for by the greater rapidity of the tests of No. 49 and No. 50, which was purposely made in order to eliminate the effect of flow of the metal with time. The pieces of No. 46 being of small ductility, the effect of time was not so perceptible.

The fractures of No. 46 were very similar to those of No. 45, showing want of homogeneity of structure, part being granular and part laminated. This may account for the weakness and irregularity of strength, as in the first series, the second maximum strength was associated with a homogeneous granular structure.

No. 47 (16.70 copper, 83.23 tin).—Only one piece was tested from this bar, No. 47 B, the other having been broken in handling before being tested. It had a less strength than either of the pieces of No. 46, and had a somewhat similar structure, being irregularly lamellar and crystalline.

No. 48 (11.68 copper, 88.25 tin).—The two pieces showed very little greater strength than No. 47 B. The fractures show the change in structure seen in those of the first series just before the metals begin to exhibit great ductility, being fine granular, with small brilliant points scattered over the surface.

No. 49 (6.05 copper, 93.77 tin).—Both test-pieces gave very similar results and higher than the average of No. 46, thus apparently making No. 49 the bar of second maximum strength of the series, as stated in remarks on the test of No. 46. These pieces showed great ductility, the elongations being 17 and 23 per cent. of the original length. The section was also greatly reduced, and the resistance to stress decreased before rupture, making the actual tenacity per square inch of the fractured section uncertain. The same fact has been commented upon when describing tests by tensile stress of the first series.

No. 50 (2.11 copper, 97.68 tin).—The results of the two tests of this bar were similar to those of No. 49, but they showed a somewhat less strength, with a much greater ductility, the elongations amounting to 39 and 41 per cent. The pieces were greatly reduced in diameter throughout their whole lengths, and their surfaces were much distorted and wrinkled. The strength of the bar as indicated by the tensile tests is much greater than that shown by the transverse and torsional tests, probably on account of the shorter length of time occupied by the former method of test.

TESTS BY TORSIONAL STRESS.

The tests by torsional stress of the second series of copper and tin alloys were made upon the Autographic Recording Torsion Machine described under the tests of first series. (Fig. 8, page 324.)

In making tests of ductile metals, the rate of motion given to the handle of the worm, except when a slow or a rapid motion was purposely given to determine its effect, was as uniformly as possible, one revolution in 10 seconds. As the worm-wheel contained 80 teeth, this caused a rate of motion of the axle of the worm-wheel, and of the wrench at one end of the test specimen, of one revolution in about 13 minutes. In testing the brittle metals and the ductile metals within the elastic limit the rate of motion was always much slower.

The autographic strain diagrams obtained, one for each test, accompany this report, and tables giving the strength, ductility, and resilience of each specimen as calculated from the diagrams, are appended.

The average results of all the test specimens obtained from each bar are given in the following table:

TABLE X.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Torsional Stress—Averages of Results calculated from the Autographic Strain Diagrams.

Number.	Mean composition by analysis.		Area of diagram.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility, extension of exterior fiber.	Resilience.	Number of pieces tested.	Remarks.
	Copper.	Tin.			Maximum.	At elastic limit.	Maximum.	At elastic limit.				
			Square inches.	*Degrees.*	*Inch.*	*Inch.*	*Foot-pounds.*	*Foot-pounds.*		*Foot-pounds.*		
31	99.09	0.87	1.95	37.75	0.62	0.28	66.50	31.75	0.0224	36.87	4	All pieces defective.
32	94.11	5.43	20.18	187.25	1.51	0.48	156.63	52.10	0.4318	368.33	4	
33	88.41	11.59	9.68	70.75	1.73	0.64	178.05	68.48	0.0730	175.23	4	
34	82.70	17.34	1.98	14.00	1.93	1.00	198.06	102.29	0.0032	35.85	4	
35	77.56	22.25	0.35	4.38	1.49	1.05	153.96	109.85	0.0003	6.46	4	
36	72.89	26.85	0.08	1.00	2.27	2.27	35.54	35.54	0.00003	0.89	2	
37	67.87	32.10	0.14	1.65	2.50	2.50	26.13	26.13	0.00009	1.08	2	
38	62.42	37.48	0.02	0.30	1.68	1.68	19.20	19.20	0.00001	0.15	2	
39	57.88	42.05	0.02	0.50	0.63	0.63	8.60	8.60	0.00001	0.16	1	
40	53.46	46.55	0.01	0.40	0.58	0.58	7.77	7.77	0.00001	0.08	2	
41	47.27	52.72	0.04	1.00	1.35	1.35	17.96	17.96	0.00003	0.34	2	
42	43.99	55.91	0.08	1.33	1.35	1.35	16.23	16.23	0.00006	0.60	3	
43	37.10	62.90	0.06	1.50	0.66	0.65	12.70	12.70	0.00004	0.20	4	
44	30.76	69.19	0.23	2.63	0.98	0.96	17.32	17.14	0.00014	0.74	4	
45	26.63	73.17	0.33	3.17	1.45	1.42	25.50	25.12	0.00018	1.06	3	
46	22.10	77.58	1.06	7.38	1.56	1.50	27.80	26.45	0.0012	3.31	4	
47	16.70	83.23	1.27	10.62	1.36	1.10	24.39	19.13	0.0020	3.96	4	
48	11.69	88.24	7.32	56.50	1.39	1.09	24.86	19.36	0.0471	22.93	4	
49	6.05	93.77	15.82	178.00	1.19	0.55	19.83	11.03	0.4006	50.66	4	
50	2.11	97.68	24.50	3.62	0.86	0.39	15.75	7.47	1.2189	80.15	4	

It will be seen by the above table that the tests by torsional stress confirmed the results obtained by the tests by transverse and tensile stresses, and also those obtained from the tests of the first series.

The maximum strength is given by No. 34 (82.72 copper, 17.33 tin). There is a rapid decrease of strength from No. 35 (77.56 copper, 22.25 tin) to No. 36 (72.89 copper, 26.85 tin), and then a much slower decrease to No. 40 (53.46 copper, 46.54 tin), the weakest of the series. From this point to No. 46 (21.60 copper, 77.58 tin) there is a slow and somewhat irregular increase up to a second maximum, and from No. 46 to the end of the series another decrease to the second minimum.

Referring to the autographic strain diagrams and the appended tables,

in connection with the above table of average results, the following observations may be made on the tests of the pieces from each bar.

No. 31, Plate LIV (99.09 copper, 0.87 tin).—Four pieces were tested, all of which were defective in consequence of blow-holes and the separation of the metals. The results are therefore rejected in the table of final summary of results (Table —) and from the curves of strength of the series. The fractures were copper-red, only two small spots of a yellowish alloy being found in one of them. The turned surfaces showed the same appearance which was noted under the tensile test, viz, a number of yellowish spots scattered at intervals over the otherwise uniformly copper-colored surface, indicating a separation either into two alloys, or into copper and one alloy. Its strength is very much less than that of the copper piece, No. 30, and nearly the same as that of the copper, No. 1, which was oxidized and full of blow-holes.

No. 32, Plates LIV, LV, LVI (94.10 copper, 5.43 tin).—The four pieces tested were all fair specimens and gave results which are nearly alike, the maximum torsional moments varying from 150 to 165 foot-pounds, and the angles of torsion from 153 to 207 degrees. The fractures were all similar, being of a yellowish-red color and earthy structure, and containing a few very small blow-holes.

The effect of long-continued stress was tried in the torsion tests of three pieces of No. 32, lettered A, B, C. No. 32 A was left under stress 15 minutes, and No. 32 B one hour. In each of these cases no change of the shape of the diagram could be detected, the pencil remaining in the position in which it was left during the whole time. No. 32 C was left for 26 hours, after it had been twisted through more than 100 degrees. In that time the pencil fell less than one-tenth of an inch, indicating a decrease of resistance of about 5 per cent. of the maximum stress. On resuming the test, the diagram rose again to just beyond its original height.

No. 33, Plates LVII, LVIII (88.40 copper, 11.59 tin).—The four pieces tested gave results closely agreeing with each other, showing a somewhat greater strength and a much less ductility than No. 32. The fractures were similar in color and texture to those by tensile stress. No. 33 D was left under stress for 15 hours without showing any fall in the diagram. On resuming the test the line retained the same direction it had before, thus showing no decrease of resistance with time.

No. 34, Plate LVIII (82.72 copper, 17.33 tin).—Four pieces were tested, the average result showing the highest strength of the series, thus confirming the results shown by the transverse and tensile tests. The ductility was very much less than that of No. 33, the average angle of torsion being only 14 degrees. The fractures were of a pinkish-gray color and granular structure. All of the fractures showed some dark brownish-yellow spots in the center, indicating a want of homogeneity, and possibly a lateral separation of the metals.

No. 35, Plate LVIII (77.56 copper, 22.25 tin).—Four pieces were tested, giving results which varied considerably, the torsional moment of No. 35 B being 215 foot-pounds, and that of No. 35 C 104 foot-pounds. The lower strength of No. 35 C and No. 35 D may possibly be accounted for by the method of making the tests, as with these pieces a special experiment was made with the machine to determine the character of the diagram made by a very rapid motion while a brittle piece was under stress. The effect is seen in the curvature toward the horizontal of the diagram of No. 35 C, and in the irregularity of the diagram of No. 35 D. The average result of the four tests shows a considerably less strength than that of No. 34, as was also shown by the tensile and transverse tests.

The fractures were all similar in appearance, being of a light-gray color and very fine granular structure.

No. 36, Plate LIX (72.89 copper, 26.85 tin).—Two pieces only were tested from this bar. It was so hard and brittle that it could not be turned in the lathe without danger of breaking. The torsion pieces were therefore shaped by grinding on an emery wheel, as were those from No. 37 to No. 41. They were ground merely to a circular section of a little less than one inch in diameter. The strength as obtained from the diagram is reduced to equivalent strength of a piece of standard size (0.625 inch diameter) by dividing by the ratio of the cube of the diameter of the piece tested to the cube of 0.625.

The two pieces from bar No. 36 gave nearly similar results, the strength being less than one-fourth of that of the average of No. 35. The diagrams, like all those of brittle materials, are almost straight lines slightly inclined from the vertical. The fractures are of a very light pinkish-gray color, and show some appearance of radiated laminæ similar to the fractures by transverse and tensile stresses.

No. 37, Plate LIX (67.87 copper, 32.09 tin).—Two pieces were tested which gave considerably less strength than No. 36. The fractures were brilliant silver white, vitreous and conchoidal.

No. 38, Plate LIX (62.42 copper, 37.48 tin).—Two pieces were tested, one from the bottom and one from the top, which gave widely different results. No. 38 A showed a torsional strength of 35.44 foot-pounds of moment (when reduced to the standard), which is nearly that of the average of the pieces from No. 36. The fracture was almost precisely similar to that of No. 37. No. 38 B gave only 2.95 foot-pounds torsional moment, which is much lower than that of any piece yet noted. Its fracture showed it to be an entirely different metal from No. 38 A, being dark gray in color and stony in structure, closely resembling in appearance the fracture of No. 12 (62.31 copper, 37.35 tin) of the first series, the bar of maximum density as before described. It was not, however, perfectly homogeneous in color, some portions being of a lighter shade of gray than others and less brilliant.

The liquation of the metals in this bar has already been noticed, and the torsion tests fully confirm the record of the tests by tension, No. 38 B showing the lowest tensile strength of the series. The average of the two results gives a strength less than that of No. 37 and greater than that of No. 39, thus making no irregularity in the table of averages, given above.

No. 39, Plate LIX (57.87 copper, 42.05 tin).—Only one piece was tested from this bar, the other pieces having been broken in turning or shaping on the emery wheel. Its strength was much less than the average of the two pieces of No. 38. The fracture was of a light-gray color, with a stony structure, and with radiated lines of cooling.

No. 40, Plate LIX (53.46 copper, 46.54 tin).—Two pieces were tested, giving an average strength less than that of No. 39, and the lowest of the series. The fractures were scarcely distinguishable from that of No. 39.

No. 41, Plate LIX (47.27 copper, 52.72 tin).—Two pieces were tested, giving results nearly alike, the average being much higher than that of No. 40. The fractures were very similar to those of No. 39 and No. 40.

No. 42, Plate LIX (43.99 copper, 55.91 tin).—Three pieces were tested, which differed considerably in strength, the pieces A, B, and C giving torsional moments of 20.84, 16.11, and 11.75 foot-pounds, respectively. The average is less than that of No. 41, making an irregularity in the table of averages. The weakness of the pieces No. 42 B and No. 42 C

seems to be caused by a difference in structure, the fractures of these pieces showing confusedly radiated laminæ, while that of No. 42 A is compact and stony, similar to that of No. 41. The difference in strength and appearance is fully accounted for by the analyses, which show that a great amount of liquation took place in the casting of this bar, the composition of top and bottom varying more than 20 per cent.

No. 43, Plate LIX (37.10 copper, 62.90 tin).—Four pieces were tested, the metal being soft enough to be turned in the lathe to pieces of standard size. The strength was quite irregular, and the average was less than that of No. 42. The fractures were of a light-gray color, with large radiated prismatic crystals.

No. 44, Plate LX (30.76 copper, 69.19 tin).—Four pieces were tested, which gave results widely varying. No. 44 A had a maximum torsional moment of only 683 foot-pounds, and No. 44 B a moment of 30.29 foot-pounds. The average of the four pieces was much higher than that of No. 43. The fractures were all crystalline, the crystals of No. 44 A being much larger than those of the other pieces. From the fact that the torsion pieces from the upper end of each of the bars, Nos. 44, 45, 46 and 47, were weaker than those of the other pieces from the same bars, it appears probable that the weakness is due either to difference in pressures of the molten metal at the top and bottom of the mold, or to differences in the rate of cooling, or possibly to both. This irregularity of strength of all the white crystalline alloys has been noted already in the tests of the first series.

No. 45, Plate LX (26.62 copper, 73.18 tin).—Three pieces were tested, showing considerable irregularity in strength, No. 45 A having less than half of the strength of No. 45 C. The fractures were irregularly laminated and crystalline. The average strength was much higher than that of No. 44, showing the approach to the second maximum of strength.

No. 46, Plate LX (22.10 copper, 77.58 tin).—Four pieces were tested, giving an average strength greater than that of No. 45, and showing the point of second maximum strength of the series, which confirms the tests by transverse stress. The piece No. 46 A had a much less strength than either of the other pieces, but it does not affect the average sufficiently to place it below the second maximum. The fractures were similar to those of No. 45.

No. 47, Plate LX (16.70 copper, 83.23 tin).—Four pieces were tested, giving a somewhat less strength than No. 46. The piece No. 47 A had only 17.35 foot-pounds torsional moment, while the pieces B, C, and D had 27.59, 25.03, and 27.59 pounds, respectively. The fractures were largely granular in the center and laminated at the edges.

No. 48, Plate LXI (11.68 copper, 88.25 tin).—Four pieces were tested, which all gave results agreeing very closely. The average strength of the four pieces is a little higher than that of No. 47, but less than that of the three pieces of No. 47 marked B, C, D. The slight irregularity in the decrease of strength of the series from No. 46 to No. 50 is due, therefore, entirely to the exceptional weakness of No. 47 A. These pieces exhibited much greater ductility than No. 46. The fractures were in a plane perpendicular to the axis of the specimen, a characteristic of the torsional fractures of all ductile metals. They were of a light-gray color and fine granular structure.

No. 49, Plates LXI, LXII, LXIII (6.05 copper, 93.77 tin).—The four pieces gave an average strength considerably less than that of No. 48, confirming the law of gradual decrease toward the end of the series. They were very ductile, twisting through angles of from 125 to 221 degrees before breaking. The turned surfaces became much distorted and

lane surfaces of fracture were polished by rubbing together as rup- took place.

. 50, Plates LXIV, LXV, LXVI, LXVII (2.11 copper, 97.68 tin).— average strength of the four pieces tested was less than that of No. iving the point of second minimum strength of the series. The s were very ductile, twisting through 325 to 424 degrees. The d surfaces and surfaces of fracture were similar to those of No. 49. testing some of the pieces of No. 49 and No. 50, experiments were to show the effect of rapid and of slow motion, and of leaving r stress for a length of time, with the same results as were shown e tests by torsion of the ductile metals of the first series, and also he tensile and transverse tests, viz, the increase of resistance to l motion, and the decrease of resistance on being left under stress time. The diagrams show very plainly the results of these "time ."

TESTS BY COMPRESSION.

e pieces were carefully prepared, like those of the first series, of a rm size of 2 inches in height and 0.625 inch in diameter, with their made plane surfaces perpendicular to the axis. The tests were in the machine (Fig. 6, p. 316), to which an attachment had been d for the purpose. The measurements were made with great ac- y by means of the apparatus (Fig. 13) described on page 348. It found that the point and moment of contact could be determined rapidly and with even greater accuracy by connecting a battery signal and letting the contact of the end of the micrometer-screw lete the circuit.

bles are appended giving the results of the test of each bar, and ollowing table (Table X*a*) presents a summary of all results of these of alloys, and also of several extra bars of cast copper:

TABLE X*a*.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Tests by Compressive Stress.

mber.	Composition by analysis.		Load per square inch causing a compression of—			Maximum load per sq. inch.	Total compression produced by maximum load Parts of original length.	Crushing strength per square inch.	Remarks.
	Copper.	Tin.	5 per cent.	10 per cent.	20 per cent.				
			Pounds.	*Pounds.*	*Pounds.*	*Pounds.*		*Pounds.*	
.....	99.09	0.87	32,500	42,000	52,000	81,485	.4400	42,000	
.....	94.11	5.43	39,000	46,000	65,000	130,379	.4665	46,000	
.....	88.40	11.59	45,000	58,670	91,266	143,417	.3455	58,670	
.....	82.72	17.33	84,000	104,000	136,898	143,417	.1910	104,303	
.....	77.56	22.25	130,379	149,932	.....	149,932	.1013	149,932	
.....	37.10	62.90	.....	.....	.....	6,519	.0025	6,519	Cracked.
.....	30.71	69.19	.....	.....	.....	16,297	.0040	16,297	Crushed.
.....	26.62	73.18	.....	.....	.....	16,297	.0091	16,297	Do.
.....	22.10	77.58	.....	.....	.....	16,297	.0113	16,297	
.....	16.70	83.23	.....	.....	.....	9,778	.0025	9,778	
.....	11.68	88.25	.....	.....	.....	13,038	.0305	13,038	
.....	Cast copper.		30,000	36,000	50,000	104,303	.5154	36,000	Flattened.
.....	.....do.....		30,000	37,000	50,000	91,266	.4814	37,000	Do.
.....	.....do.....		35,000	48,000	65,000	97,765	.4122	48,000	Do.

he following observations were noted in connection with the individual s. The manner in which they yielded under the pressures applied to

them is shown in Plate XXI, and a record and comparison of all results of both series is given by the curves of Plate IV.

The increments of pressure upon the test pieces were 1,000 pounds for the weaker alloys and 2,000 for the stronger, which for a diameter of 0.625 correspond respectively to pressures of 3,259 and 6,519 pounds per square inch.

No. 31 (99.09 copper, 0.87 tin).—A comparison of the plotted curves of Nos. 31 and 1 (copper) shows much similarity, with an increased resistance to compression on the part of No. 31. The test was ended at a pressure of 81,485 pounds per square inch by the cracking of a wedge-shaped piece at the top and a similar one at the bottom. The compression at this point was 0.8801 inch. The piece was considerably bent. The diameter of its oval section varied from 0.79 to 0.84 inch.

No. 32 (94.11 copper, 5.43 tin).—The compression of the piece was not measurable until it had been subjected to a pressure of 19,557 pounds per square inch, which caused a compression of 0.0001 inch. At 26,075 pounds per square inch the compression was 0.0108 inch, its *apparent* elastic limit, as shown by the curve, being near this pressure. The piece was removed after being subjected to a pressure of 130,379 pounds per square inch, which caused a compression of 0.9330 inch. It was much bent. It had none but mere surface cracks. Its section was slightly oval with diameters varying from 0.80 to 0.86 inch.

No. 33 (88.40 copper, 11.59 tin).—The *apparent* elastic limit was at about 30,000 pounds per square inch. Under a pressure of 32,595 pounds per square inch the compression was 0.0374 inch. Beyond this point the amount of compression continued very nearly proportional to the pressure until a compression of 0.6911 inch under a pressure of 143,417 pounds per square inch was reached, when the piece was removed. The specimen was bent, the surface quite uniformly mottled or wrinkled, but showed no sign of fracture, and would evidently have resisted a considerably greater pressure and compression. Its section was nearly circular and had increased to a diameter of from 0.72 to 0.74 inch.

No. 34 (82.72 copper, 17.33 tin).—The first point at which a marked change in the direction of the plotted curve can be observed is at the pressure of 58,671 pounds per square inch, which gave a compression of 0.0268 inch. A pressure of 71,709 pounds per square inch caused a compression of 0.0628 inch. From this point to the end of the test the compressions, as shown by the curve, were proportional to the pressures. The greatest compression obtained was 0.3821 inch, caused by a pressure of 136,898 pounds per square inch. A pressure of 143,417 pounds per square inch caused a wedge, whose base was the full size of the diameter of the piece, to separate from the top, the pressure upon the surfaces as they slid upon each other burnishing them. A semi-cylindrical piece about 0.4 inch in height flew off from the bottom. Cracks extended upward to the middle. The piece was but slighly bent. The diameter had increased to from 0.67 to 0.69 inch.

No. 35 (77.56 copper, 22.25 tin).—This piece proved to be the strongest of either series. It withstood pressures up to 91,260 pounds per square inch and a compression of 0.0190 inch before the ratio of compression to pressure began to increase and to show that the *apparent* limit of elasticity had been passed. The piece, however, withstood, without yielding, the utmost pressure that could be brought to bear upon it by the testing-machine. The maximum compression was 0.2027 inch, produced by a pressure of 149,932 pounds per square inch. The surface was slightly wrinkled and showed a few surface cracks. A bend could be just dis-

inguished. The section remained circular and measured 0.69 inch in liameter.

No. 36 (72.89 copper, 26.85 tin) to No. 42 (43.99 copper, 55.91 tin) gave no definite results, as they crumbled under slight pressure.

No. 43 (37.10 copper, 69.19 tin).—This piece was weak and brittle. A pressure of 6,519 pounds caused a compression of 0.0051 inch. On adding the next weight, which brought to bear a pressure of 13,038 pounds per square inch, the bottom crumbled into fragments. The upper portions were unchanged in appearance or size.

No. 44 (30.76 copper, 69.19 tin) behaved in the same manner as No. 43. It was somewhat stronger, sustaining a pressure of 13,038 pounds per square inch and a corresponding compression of 0.0081 inch. A pressure of 16,297 pounds per square inch was brought upon it, which it resisted just long enough to lift the scale-beam, when it yielded by pieces breaking from the top. The surface presented a slightly wrinkled appearance and the diameter was increased to 0.61 inch.

No. 45 (26.62 copper, 73.18 tin) was similar to No. 44, but somewhat more yielding, a pressure of 13,038 pounds compressing it 0.0182 inch. A pressure of 16,297 pounds per square inch had just raised the scale-beam, when pieces broke from the middle of the specimen. The diameter and the appearance of the remaining portion was unchanged.

No. 46 (22.10 copper, 77.58 tin) behaved much like Nos. 44 and 45, but showed a little more ductility. A pressure of 13,038 pounds per square inch caused a compression of 0.0227 inch. It was crushed by a pressure of 16,297 pounds, which forced off wedge-shaped pieces near the bottom. The upper portion of the specimen was not changed in diameter or appearance.

No. 47 (16.70 copper, 83.23 tin) was weak and brittle; a pressure of 6,519 pounds per square inch caused a compression of 0,0051 inch. Under a pressure of 9,778 pounds per square inch wedge-shaped pieces broke out from the middle.

No. 48 (11.68 copper, 88.25 tin).—This piece was very weak, but less brittle than the four preceding specimens. A pressure of 9,778 pounds per square inch compressed it 0.0611 inch. A pressure of 13,038 pounds per square inch caused it to yield in three portions; the top and bottom parts being wedge-shaped, with the points of the wedges meeting, and having bases the full size of the diameter of the specimen, and the remaining or middle portion being in one piece, and the whole welded together.

No. 51 (cast copper).—A pressure of 19,557 pounds per square inch caused a compression of 0.0089 inch. A pressure of 26,075 pounds per square inch caused a compression of 0.0573 inch. The change in the curve which seemed to mark the elastic limit occurs between these two. Beyond the last-named observation, and until the piece was removed, the ratio of compression to pressure continued nearly constant, as is shown by the plotted record, which is nearly a straight line up to the point corresponding to a pressure of 71,705 pounds per square inch, where an increase of resistance is observed. The maximum pressure was 104,303 pounds per square inch and the maximum compression was 1.0308 inch.

No. 52 (cast copper) offered a resistance very similar to No. 51. The apparent elastic limit was between the same pressures. The pressure was carried up to 91,266 pounds per square inch, causing a compression of 0.9628 inch. The piece flattened and bent considerably. The section was oval, and the diameters varied from 0.84 to 0.91 inch.

No. 53 (cast copper) showed greater resistance to compression than either Nos. 51 and 52. A change in direction of the plotted curve occurs

at the same pressures as noted in the last-named tests, but it is not marked, the line showing a gradual curve up to 55,000 pounds per square inch. The maximum pressure applied was 97,785 pounds per square inch, and the compression caused by that pressure was 0.824 inch.

ANALYSES AND SPECIFIC GRAVITIES.

The following tables give the results of the chemical analyses and determinations of specific gravity which were made of portions of each bar tested, in both the first and second series.

The analyses were made from the turnings and chips made in shaping the specimens for test by tensile stress, two samples for analysis being thus taken from each bar. In some cases in which liquation was plainly seen from the appearance of the fracture, analyses were made of three portions of the bar.

The specific gravity determinations were made of pieces weighing from 50 to 75 grammes, taken from the cylindrical portion of the broken tensile-test pieces. The pieces of the more ductile specimens were taken from the portion of the test-piece farthest from the point of fracture and therefore least distorted by the stress. Care was taken to secure pieces as free from blow-holes as possible, but in some cases this could not be done, and the results are therefore too low, as those which are indicated in the tables by an asterisk.

In determining the specific gravities, the pieces were first washed in alcohol to free them from any dirt or grease which might be attached to them, and then thoroughly dried. The weighings were made on a Becker & Sons's chemists' balance, which was sensitive to $\frac{1}{10}$ of a milligramme. Before weiging in water, the pieces were boiled for two or three hours, to remove as far as possible the air inclosed in the pores of the metal, and after cooling in the dish in which they were boiled, they were placed under the receiver of an air-pump, and the air was further exhausted. They were then rapidly transferred to the beaker of distilled water, in which they were weighed, being suspended by a loop of very fine platinum wire from the arm of the balance. The water in which they were weighed was always kept at the same level, and the proper correction was made for the weight of the platinum wire.

The results given in the table are corrected for the temperature of the water, being reduced to the standard of water of maximum density (39°.1 Fahr.).

It will be seen that the bars which have been described under the remarks on the tests as being full of blow-holes give low specific gravities, and it seems probable that all the figures of all the bars, from No. 1 to No. 9 and No. 30 to No. 34, are lower than the true specific gravities of the metal.

To determine the effect of the porous structure in reducing the apparent specific gravity, a special determination was made of No. 6 A (87.1 copper, 12.69 tin) in the shape of turnings. It will be remembered that the test specimen with this number showed a separation of the metal into two distinct alloys, which appeared intimately mixed in the fracture surface. The piece whose specific gravity was determined to be only 8.408 as given the tables, was apparently free from blow-holes of any appreciable size, but the fracture had a porous appearance. Five turnings were made from the same piece, and their density was determined by the specific-gravity bottle, and also by weighing them in water in a small dish of platinum foil suspended from the arm of the balance. Considerable difficulty was experienced in removing the air-bubbles, and in

as only after several boilings and exhaustions with the air-pump that nstant weighings were obtained, the apparent specific gravity increasg as the air was more perfectly removed. The result finally obtained as a density of 8.943, corrected for the expansion of water, and this figre was obtained by both methods.

The density of turnings from the ingot-copper used in making the loys was in like manner determined to be 8.874.

A marked difference is seen between the density of the copper bar lo. 1 and that of No. 30, which corresponds to their difference in other roperties.

In averaging the figures obtained for the column of mean specific gravity Nos. 2 A, 6 A, and 31 A are rejected, as the figures obtained for them re evidently much lower than their true specific gravities.

The bars which exhibited liquation also show a great difference in pecific gravity in the top and bottom of the bar, corresponding to the lifference in composition.

In bar No. 38 (62.42 copper, 37.48 tin), the mean specific gravity is taken to be that of the piece from the middle of the bar No. 38 C, as the composition of this piece agrees more nearly than the other portions of the bar with the original mixture, and this composition nearly corresponds to the maximum density shown by No. 12.

TABLE XI.—FIRST SERIES—ALLOYS OF COPPER AND TIN.

Analyses and Specific Gravities.

Number.	Original mixture.		Analysis.		Variation of composition.		Mean analysis.		Specific gravity.	Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.		
1 A	100.00	0.00	.....	.....	.....	.....	.....	.....	.....	8.487*
B	100.00	0.00	.....	.....	.....	.....	.....	.....	8.487*	
2 A	98.10	1.90	97.95	1.88	− 0.15	− 0.02	97.89	1.90	8.092*	8.564
B	98.10	1.95	97.83	1.92	− 0.27	+ 0.02			8.564	
3 A	96.27	3.73	96.16	3.71	− 0.11	− 0.02	96.06	3.76	8.599	8.600
B	96.27	3.73	95.96	3.80	− 0.31	+ 0.07			8.599	
4 A	92.80	7.20	92.14	7.84	− 0.56	+ 0.64	92.11	7.80	8.608	8.604
B	92.80	7.20	92.07	7.76	− 0.73	+ 0.56			8.720	
5 A	90.00	10.00	90.11	9.66	+ 0.11	− 0.34	90.27	9.58	8.635	8.699
B	90.00	10.00	90.43	9.50	+ 0.43	− 0.50			8.703	
6 A	86.57	13.43	87.15	12.69	+ 0.58	− 0.74	87.15	12.73	8.408*	8.681
B	86.57	13.43	87.15	12.77	+ 0.58	− 0.66			8.681	
7 A	80.00	20.00	80.99	18.92	+ 0.99	− 1.08	80.95	18.84	8.759	8.740
B	80.00	20.00	80.90	18.75	+ 0.90	− 1.25			8.721	
8 A	76.32	23.68	76.67	23.24	+ 0.35	− 0.44	76.64	23.24	8.558*	8.562*
B	76.32	23.68	76.60	23.23	+ 0.28	− 0.45			8.573*	
9 A	70.00	30.00	69.90	29.85	− 0.10	− 0.15	69.84	29.89	8.935	8.933
B	70.00	30.00	69.77	29.92	− 0.23	− 0.08			8.928	
10 A	68.25	31.75	68.59	31.21	+ 0.34	− 0.54	68.58	31.26	8.938	8.939
B	68.25	31.75	68.57	31.30	+ 0.32	− 0.45			8.937	
11 A	65.00	35.00	65.31	34.47	+ 0.31	− 0.53	65.34	34.47	8.924	8.947
B	65.00	35.00	65.36	34.47	+ 0.36	− 0.53			8.969	
12 A	61.71	38.29	61.83	37.74	+ 0.12	− 0.55	62.31	37.35	8.971	8.970
B	61.71	38.29	62.79	36.96	+ 1.08	− 1.33			8.969	
13 A	56.32	43.68	56.58	43.11	+ 0.26	− 0.57	56.70	43.17	8.728	8.682
B	56.32	43.68	56.82	43.22	+ 0.50	− 0.46			8.635	
14 A	51.80	48.20	62.27	37.58	+10.47	−10.62	51.62	48.09	8.944	8.760
C	51.80	51.80	38.41	61.04	−13.39	+12.84			8.202	
B	51.80	48.20	51.62	48.09	− 0.18	− 0.11			8.533	
15 A	47.95	52.05	47.72	51.99	− 0.23	− 0.06	47.61	52.14	8.462	8.449
B	47.95	52.05	47.49	52.29	− 0.46	+ 0.24			8.442	
16 A	44.63	55.37	44.62	55.15	− 0.01	− 0.22	44.52	55.28	8.395	8.319
B	44.63	55.37	44.42	55.41	− 0.21	+ 0.04			8.229	
17 A	41.74	58.26	45.93	53.80	+ 4.19	− 4.46	42.38	57.20	8.523	8.269
B	41.74	58.26	38.83	60.79	− 2.91	+ 2.53			8.081	
18 A	39.20	60.80	43.37	56.37	+ 4.17	− 4.43	38.37	61.32	8.160	8.182
C	39.20	39.20	38.37	61.32	− 0.83	+ 0.52			.....	
B	39.20	60.80	43.36	56.40	+ 4.16	− 4.40			8.203	
19 A	34.95	65.05	40.32	59.46	+ 5.37	− 5.59	34.22	65.80	8.036	8.013
C	34.95	34.95	34.22	65.80	− 0.73	+ 0.75			.....	
B	34.95	65.05	40.24	59.44	+ 5.29	− 5.61			7.989	
20 A	28.72	71.28	26.57	73.08	− 2.15	+ 1.80	25.85	73.80	7.956	7.948
B	28.72	71.28	25.12	74.51	− 3.60	+ 3.23			7.940	
21 A	24.38	75.62	22.80	76.89	− 1.58	+ 1.27	23.35	76.29	7.813	7.893
B	24.38	75.62	23.89	75.68	− 0.49	+ 0.06			7.856	
22 A	21.18	78.82	20.28	79.63	− 0.90	+ 0.81	20.25	79.63	7.757	7.770
B	21.18	78.82	20.21	79.62	− 0.97	+ 0.80			7.783	
23 A	15.19	84.81	15.12	84.58	− 0.07	− 0.23	15 08	84.62	7.669	7.657
B	15.19	84.81	15.04	84.65	− 0.15	− 0.16			7.644	
24 A	11.84	88.16	11.49	88.44	− 0.35	+ 0.28	11.49	88.47	7.521	7.538
B	11.84	88.16	11.48	88.50	− 0.36	+ 0.34			7.582	
25 A	9.70	90.30	8.82	91.12	− 0.88	+ 0.82	8.57	91.39	7.515	7.487
B	9.70	90.30	8.32	91.66	− 1.38	+ 1.36			7.459	
26 A	4.29	95.71	3.70	96.30	− 0.59	+ 0.59	3.72	96.31	7.401	7.360
B	4.29	95.71	3.74	96.32	− 0.55	+ 0.61			7.318	
27 A	1.11	98.89	0.75	98.98	− 0.36	+ 0.09	0.74	99.02	7.311	7.305
B	1.11	98.89	0.72	99.06	− 0.39	+ 0.17			7.299	
28 A	0.557	99.443	0.32	99.46	− 0.237	+ 0.017	0.32	99.46	7.299	7.299
B	0.557	99.443	0.32	99.45	− 0.237	+ 0.007			7.299	
29 A	0.00	100.00	.....	.....	.....	.....	.....	.....	7.297	7.293
B	0.00	100.00	.....	.....	.....	.....	.....	.....	7.289	
30 A	100.00	0.00	.....	.....	.....	.....	.....	.....	8.797	8.791
B	100.00	0.00	.....	.....	.....	.....	.....	.....	8.785	

*The figures marked with a star in the columns of specific gravities are much lower than the true specific gravities, in consequence of the presence of blow-holes. The specific gravity of No. 6 A was re-determined in the shape of fine turnings, and found to be 8.943. A determination of the specific gravity of fine turnings of the ingot-copper used in this series was also made, giving the result 8.874.

TABLE XII.—SECOND SERIES—ALLOYS OF COPPER AND TIN.

Analyses and Specific Gravities.

er.	Original mixture.		Analysis.		Variation of composition.		Mean analysis.		Specific gravity.	Mean specific gravity.
	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.	Copper.	Tin.		
.....	97.5	2.5	99.40	0.52	+1.90	−1.98	99.09	0.87	8.511	8.511
.....	97.5	2.5	98.79	1.22	+1.29	−1.28			*8.251	
.....	92.5	7.5	93.98	5.47	+1.48	−2.03	94.11	5.43	8.704	8.684
.....	92.5	7.5	94.23	5.39	+1.73	−2.11			8.664	
.....	87.5	12.5	88.35	11.61	+0.85	−0.89	88.41	11.59	8.650	8.648
.....	87.5	12.5	88.46	11.57	+0.96	−0.93			8.645	
.....	82.5	17.5	82.72	17.33	+0.22	−0.17	82.70	17.34	8.794	8.792
.....	82.5	17.5	82.69	17.34	+0.19	−0.16			8.789	
.....	77.5	22.5	77.41	22.27	−0.09	−0.23	77.56	22.25	8.935	8.917
.....	77.5	22.5	77.71	22.23	+0.21	−0.27			8.899	
.....	72.5	27.5	72.85	26.80	+0.35	−0.70	72.89	26.85	8.925	8.925
.....	72.5	27.5	72.94	26.90	+0.44	−0.60			8.925	
.....	67.5	32.5	67.66	32.32	+0.16	−0.28	67.87	32.10	8.914	8.907
.....	67.5	32.5	68.08	31.98	+0.58	−0.52			8.900	
.....	62.5	37.5	67.59	32.32	+0.509	−5.18	62.42	37.48	8.863	8.956
.....	62.5	62.5	63.69	36.27	+1.19	−1.23			8.956	
.....	62.5	37.5	55.99	43.85	−6.51	+6.35			8.744	
.....	57.5	42.5	64.21	35.56	+6.71	−6.94	57.88	42.05	8.874	8.781
.....	57.5	57.5	.....	.....	.....	.....			8.831	
.....	57.5	42.5	51.54	48.54	−5.96	+6.04			8.637	
.....	52.5	47.5	56.83	43.21	+4.33	−4.04	53.46	46.55	8.779	8.643
.....	52.5	47.5	50.10	49.88	−2.40	+2.38			8.507	
.....	47.5	52.5	47.10	52.86	−0.40	+0.36	47.27	52.72	8.461	8.446
.....	47.5	52.5	47.43	52.59	−0.07	+0.09			8.430	
.....	42.5	57.5	55.21	44.80	+12.71	−12.70	43.99	55.91	8.461	8.437
.....	42.5	57.5	32.77	67.02	−9.73	+9.52			8.412	
.....	37.5	62.5	37.62	62.36	+0.12	−0.14	37.10	62.90	8.112	8.101
.....	37.5	62.5	36.58	63.44	−0.92	+0.94			8.090	
.....	32.5	67.5	33.86	66.01	+1.36	−1.49	30.76	69.19	7.931	7.931
.....	32.5	67.5	27.66	72.37	−4.84	+4.87			7.776	
.....	27.5	72.5	26.64	73.15	−0.86	+0.65	26.63	73.17	7.945	7.915
.....	27.5	72.5	26.61	73.20	−0.89	+0.70			7.885	
.....	22.5	77.5	22.09	77.62	−0.41	+0.12	22.10	77.58	7.807	7.774
.....	22.5	77.5	22.11	77.54	−0.39	+0.04			7.741	
.....	17.5	82.5	16.74	83.11	−0.76	+0.61	16.70	83.23	7.685	7.690
.....	17.5	82.5	16.66	83.36	−0.84	+0.86			7.695	
.....	12.5	87.5	11.67	88.25	−0.73	+0.75	11.69	88.24	7.549	7.543
.....	12.5	87.5	11.70	88.24	−0.80	+0.74			7.536	
.....	7.5	92.5	6.07	93.75	−1.43	+1.25	6.05	93.77	7.403	7.417
.....	7.5	92.5	6.03	93.79	−1.47	+1.29			7.430	
.....	2.5	97.5	2.18	97.60	−0.32	+0.10	2.11	97.68	7.339	7.342
.....	2.5	97.5	2.03	97.77	−0.47	+0.27			7.344	

GENRAL SUMMARY OF RESULTS.

following table exhibits a condensed summary of results of all the hich have been made in both series arranged in the order of their sition by original mixture.

results under the heads of "Tests by tensile stress" and "Tests sional stress" are the averages of the results of the tests of the two specimens bearing the same numbers, but in all cases rejecting f defective specimens except bar No. 1, which is retained for com- n with bar No. 30.

TABL XIII.—FIRST AND SECOND SERIES.—ALLOYS OF COPPER AND TIN.

Summary of Average Results.

Number.	Atomic proportion.	Composition of original mixture.		Mean composition by analysis.		Mean specific gravity.	Tests by transverse stress.					Tests by tensile stress.					Compression tests.		Tests by torsional stress.				
		Copper.	Tin.	Copper.	Tin.		Modulus of rupture.	Elastic limit, in parts of breaking load.	Total deflection before breaking.	Resilience within a deflection of ¾ inches.	Modulus of elasticity.	Tensile strength p. sq. inch of— Original section.	Tensile strength p. sq. inch of— Fractured section.	Elastic limit, percentages of breaking load.	Total elongation, in parts of original length.	Diameter of fractured section, percentages of original.	Crushing strength, pounds per square inch.	Amount of compression, percentages of original length.	Torsional moment. Maximum.	Torsional moment. Elastic limit, percentages of maximum.	Ductility. Angle of torsion.	Ductility. Extension of exterior fiber.	Resilience.
							Inch's	*Ft.lbs.*				*Pounds*	*Pounds.*						*Foot lbs.*				
1*	Cu	100.00	0.00	.....	.....	8.487	21,251	.316	2.306	114.8	13,986,605	12,760	12,987	.862	.0047	.96	39,000	.10+	65.66	.505	40.50	0.0255	37.71
30	Cu	100.00	0.00	.....	.....	8.791	29,848	.140	Bent	191.25	10,203,205	27,800	32,496	.518	.0647	.92	42,000	.10+	143.24	.353	153.00	0.3084	320.35
2	$Sn\ Cu_{96}$	98.10	1.90	97.89	1.90	8.564	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	34,000	.10+	150.46	.248	317.50	1.0006	572.51
31*	.....	97.50	2.50	99.09	0.87	8.511	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	$Sn\ Cu_{68}$	96.27	3.73	96.06	3.76	8.649	33,232	.350	Bent	239.68	13,739,654	32,000	42,692	.500	.1429	.86	42,000	.10+	156.93	.338	247.40	0.7031	599.96
4	$Sn\ Cu_{34}$	92.80	7.20	92.11	7.80	8.694	43,731	.426	Bent	310.58	14,263,420	28,540	33,780	.666	.0533	.92	42,000	.10+	160.01	.383	125.60	0.2189	277.22
32	.....	92.50	7.50	94.11	5.43	8.684	38,659	.370	Bent	264.20	13,581,817	27,900	34,383	.502	.0743	.88	.....	.....	156.64	.333	187.25	0.4318	368.33
5	.....	90.00	10.00	90.27	9.58	8.669	49,400	.400	Bent	345.01	14,012,135	26,860	30,205	.586	.0366	.93	38,000	.10+	175.28	.414	114.50	0.1795	274.60
33	.....	87.50	12.50	88.41	11.59	8.648	60,403	.353	4.000	415.14	12,472,655	31,100	33,153	.675	.0356	.97	.....	.....	178.05	.385	70.75	0.0730	175.23
6	$Sn\ Cu_{12}$	86.57	13.43	87.15	12.73	8.681	.....	.....	2.291	155.70	.....	29,430	30,680	.680	.0333	.98	53,000	.10+	182.32	.446	100.00	0.1391	253.61
34	.....	82.50	17.50	82.70	17.34	8.792	67,930	.565	0.625	57.75	15,152,664	36,200	36,346	.....	.0071	1.00	.....	.....	198.06	.516	14.00	0.0032	35.85
7	.....	80.00	20.00	80.95	18.84	8.740	56,715	.657	0.492	44.30	13,304,198	32,980	34,980	.....	.0040	1.00	78,000	.10+	190.15	.623	16.30	0.0040	35.59
35	.....	77.50	22.50	77.56	22.25	8.917	29,926	1.00	0.161	5.62	15,149,535	24,650	24,650	1.00	.0054	1.00	.....	.....	153.96	.714	4.38	0.0003	6.46
8	$Sn\ Cu_6$	76.32	23.68	76.64	23.24	8.565	32,210	1.00	0.191	8.17	13,495,122	22,010	22,010	1.00	.....	1.00	114,081	.0905	122.13	1.00	3.40	0.0002	3.72
36	.....	72.50	27.50	72.89	26.85	8.925	9,512	1.00	0.048	0.57	16,387,041	6,493	6,493	1.00	.....	1.00	.....	.....	35.54	1.00	1.00	0.00003	0.89
9	.....	70.00	30.00	69.84	29.89	8.932	12,076	1.00	0.062	0.97	15,321,736	5,585	5,585	1.00	.....	1.00	146,676	.0350	17.58	1.00	1.50	0.00008	0.63
10	$Sn\ Cu_4$	68.25	31.75	68.58	31.26	8.938	9,192	1.00	0.043	0.58	15,694,556	1,620	1,620	1.00	.....	1.00	.....	.....	.....	.....	.....	.....	.....
37	.....	67.50	32.50	67.87	32.10	8.907	9,477	1.00	0.052	0.58	14,896,691	2,536	2,536	1.00	.....	1.00	.....	.....	26.13	1.00	1.65	0.00009	1.08
11	.....	65.00	35.00	65.34	34.47	8.947	4,776	1.00	0.030	0.12	19,344,368	2,201	2,201	1.00	.....	1.00	84,747	.0285	16.44	1.00	0.75	0.00002	0.36
38	.....	62.50	37.50	62.42	37.48	8.956	2,907	1.00	0.019	0.17	.....	1,561	1,561	1.00	.....	1.00	.....	.....	19.20	1.00	0.50	0.00001	0.15
12	$Sn\ Cu_3$	61.71	38.29	62.31	37.35	8.970	2,761	1.00	0.032	0.12	9,603,989	688	688	1.00	.....	1.00	39,114	.0175	7.06	1.00	1.00	0.00003	0.25
39	.....	57.50	42.50	57.88	42.05	8.781	3,732	1.00	0.021	0.12	.....	1,377	1,377	1.00	.....	1.00	.....	.....	8.60	1.00	0.50	0.00001	0.16
13	$Sn_5\ Cu_{13}$	56.32	43.68	56.70	43.17	8.684	2,126	1.00	0.010	0.01	14,693,513	1,455	1,455	1.00	.....	1.00	.....	.....	8.94	1.00	1.00	0.00003	0.41
40	.....	52.50	47.50	53.46	46.55	8.643	1,995	1.00	0.008	0.03	.....	.....	.....	.....	.....	.....	.....	.....	7.77	1.00	0.40	0.00001	0.08
14	$Sn\ Cu_2$	51.80	48.20	51.62	48.09	8.596	3,877	1.00	0.010	0.23	.....	2,535	2,535	1.00	.....	1.00	.....	.....	13.54	1.00	1.00	0.00003	0.19

45	.....	27.50	72.50	24.63	73.17	7.915	11,158	.442	0.220	3.62	7,863,107	4,380	4,380	....	.....	1.00	.....	.....	25.50	.983	3.14	0.0018	2.77
21	Sn_3Cu_2 ...	24.30	75.62	23.35	76.29	7.835	12,408	.378	0.269	5.33	11,520,262	6,775	6,775	....	.....	1.00	.....	.....	41.50	.979	4.56	0.1003	2.25
46	.....	22.50	77.50	22.10	77.58	7.774	13,687	.300	0.405	8.78	8,474,849	5,000	5,014	....	.0028	1.00	.....	.....	27.80	.951	7.38	0.0012	3.31
22	Sn_2Cu ...	21.18	78.82	20.25	79.63	7.770	10,019	.333	0.345	5.37	9,743,644	4,337	4,337	.....	....	1.00	16,227	.10+	22.93	.930	5.60	0.0006	2.07
47	.....	17.50	82.50	16.70	83.23	7.690	10,288	.267	0.533	11.51	7,356,258	2,816	2,822	.....	.....	1.00	.....	.....	24.39	.784	10.62	0.0020	3.96
23	Sn_3Cu ...	15.19	84.81	15.08	84.62	7.657	9,063	.222	0.858	12.8	7,032,130	6,520	6,520	.844	.0067	1.00	6,519	.10+	22.80	.753	24.83	0.0092	9.05
48	.....	12.50	87.50	11.69	88.24	7.543	10,254	.200	1.076	21.42	7,901,458	3,798	3,825	.527	.005	.99	.....	.....	24.86	.779	56.50	0.0471	22.93
24	Sn_4Cu	11.84	88.16	11.49	88.47	7.552	10,706	.250	Bent	76.72	10,403,101	6,380	6,627	.549	.0410	.98	10,104	.10+	23.24	.653	61.75	0.0708	23.45
25	Sn_5Cu ...	9.10	90.30	8.57	91.39	7.487	5,305	.250	Bent	43.72	7,965,984	6,450	7,594	.543	.0687	.92	.....	.....	22.98	.631	131.75	0.2347	43.85
49	.....	7.50	92.50	6.05	93.77	7.417	9,764	.207	Bent	73.79	7,969,719	6,096	8,121	.427	.2022	.87	.....	.....	19.83	.556	178.00	0.4006	50.66
26	$Sn_{12}Cu$ ...	4.29	95.71	3.72	96.31	7.360	6,925	.190	Bent	39.75	8,613,200	4,780	6,814	.575	.1232	.84	.....	.....	22.83	.514	220.50	0.5677	76.23
50	.....	2.50	97.50	2.11	97.68	7.342	8,374	.240	Bent	63.64	6,692,585	5,600	12,397	.214	.4000	.65	.....	.....	15.75	.474	362.00	1.2189	80.15
27	$Sn_{24}Cu$ ...	1.11	98.89	0.74	99.02	7.305	3,964	.333	Bent	33.16	6,771,517	3,650	7,867	....	.2277	.70	.....	.....	18.29	.448	387.50	1.3388	90.40
28	$Sn_{36}Cu$ ...	0.5	99.44	0.32	99.46	7.299	4,435	.308	Bent	29.94	9,398,659	4,475	13,223	.556	.3544	.58	.....	.....	16.47	.418	535.30	2.0879	125.99
29	Sn	0	.00	.....	.....	7.293	3,740	.273	Bent	29.75	6,734,838	3,500	.....	.476	.3551	.50	6,400	.10+	12.75	.453	556.75	2.1975	105.45

* Defective bar. † Defective transverse bar.
‡ Specific gravity of turnings of ingot-copper, 8.874; specific gravity of turnings of No. 6 A, 8.943.
§ Short bar.

REMARKS UPON THE GENERAL SUMMARY OF RESULTS.

From the results recorded in the above table a number of curves have been plotted (Plates VII to XI), by inspection of which the relations existing between the compositions of the alloys of copper and tin, their density, strength, ductility, and other properties, may be seen more plainly than from the figures. These curves, and the figures from which they were plotted, will now be discussed in order.

VARIATION OF COMPOSITION BY ANALYSIS FROM COMPOSITION BY ORIGINAL MIXTURE, AND LIQUATION OR SEPARATION OF THE METALS.

From the figures given in the tables of analyses and specific gravities (pages 372, 373), under the head of "Variation of composition," a diagram has been plotted to show what relation, if any, this variation of composition bears to the percentages of copper and tin in the original mixture. The diagram does not indicate, however, that this variation follows with certainty any regular law dependent upon the percentage of the metals. In general there appears to be a greater loss of tin than of copper in the bars which contain the greater percentages of copper, and a greater loss of copper than of tin in the bars which contain the larger percentages of tin, and that the bars which contain about equal amounts of the two metals show great tendency to liquation.

In the alloys which contain less than 35 per cent. of tin by original mixture there is a greater loss of tin than of copper, with but three exceptions. In the alloys containing more than 70 per cent. of tin there is a greater loss of copper than of tin, with only one exception. In all of the alloys of these two classes the extreme variation of a single analysis from the original mixture is 3.6 per cent., and generally it is less than one per cent. In the alloys between these limits, or those containing between 35 and 70 per cent. of tin, there are some bars which show great amounts of liquation, and others which show very little. The diagram at this portion of the series is consequently very irregular, and fails to indicate any definite law.

It only seems to show that in these compositions there is a great tendency to liquation, which may or may not take place, according as certain precautions are observed in casting. In the bars whose analyses showed a great amount of liquation it was uniformly the case that the upper part of the bar contained the larger percentage of copper, and from the appearances of the fractures of different portions, the variations in hardness and other properties, as well as some analyses and determinations of density made of different portions of the bar, it appears that there was a regular increase in percentage of copper from the bottom to the top, and that there was no distinct plane of separation between two different but definite compositions. In two cases the differences in composition of the top and bottom of the bar amounted to more than 20 per cent.

In two cases there appeared to be lateral liquation or separation of the metals in such a manner that the exterior of the bar contained a less amount of tin than the interior. The first of these, No. 18 (38.37 copper, 61.32 tin), contained by original mixture 39.20 copper, 60.80 tin. The analyses of the turnings from the tension-pieces, from the top and from the bottom of the bar, the turnings being taken from the whole length of the cylindrical portions of the test-pieces, and including all of the metal in the square portion of the bar except the cylinder in the

center, 0.798 inch in diameter, gave almost precisely the same results (43.37 copper, 56.37 tin, and 43.36 copper, 56.40 tin), showing a loss of tin of more than 4 per cent. A piece from the middle of the bar was then analyzed, the whole of the square section being turned into chips. The analysis of this piece gave 38.37 copper, 61.32 tin, or 0.52 per cent. more tin than the original mixture. The other bar, No. 19, showed the same result. The original mixture was 34.95 copper, 65.05 tin, and the analyses of the turnings from the outside of the bar at top and bottom were 40.32 copper, 59.46 tin, and 40.24 copper, 59.44 tin. The analysis of a piece from the middle of the bar gave 34.22 copper, 65.80 tin.

SPECIFIC GRAVITY.

The curve of specific gravities shows a certain degree of regularity, indicating that the densities of these alloys follow a definite law.

The alloys containing less than 25 per cent. of tin show an irregular variation in specific gravity, but this is entirely explained by the fact of the porosity of the metals, and that the determinations were made on large pieces. The figures obtained are, therefore, to be considered as the densities of the *castings*, and not of the metals themselves, as they might be determined in the shape of fine powder, or metal perfectly free from minute cavities.

The densities of the castings are much lower than that of the metal as given by other authorities, and this fact is corroborated by the determinations of the density of No. 6 A (87.15 copper, 12.69 tin) in the shape of fine turnings, which gave the figure 8.943, and of turnings of ingot-copper, which gave the figure 8.874.

It will be noticed that those bars which gave less strength than might be expected from their compositions, and those whose resistances to stress are rejected from the table of averages, also had lower specific gravities than those metals of nearly similar compositions which had greater strength.

From the comparison of the strengths of the bars containing less than 20 per cent. of tin with their densities, it is apparent that the strength and density are in a certain degree dependent upon each other; that is, that the greater the density of an alloy of any given composition containing less than 20 per cent of tin the greater the strength. This has been plainly shown in experiments by several authorities on gun-metal, which uniformly exhibits an increase of strength with increase of density.

This fact will also account for the much lower strength of the alloy of 90 copper, 10 tin, and of metals of nearly similar composition, than is given by some authorities as the strength of gun-metal. It must be remembered that the casting of small bars, such as have been used in the experiments herein described, is especially unfavorable to the production of metal of great density, while in the casting of guns and other large masses the pressure of molten metal is much greater, and all conditions favor the increase of density.

From a study of the specific gravities of alloys of copper and tin which have been published by other authorities, especially Calvert and Johnson, and Riche, who took especial precautions to obtain the densities of the compacted metals, and comparing them with the figures given above for ingot-copper and No. 6 A in turning, it appears probable that the actual specific gravities of all the alloys containing less than 25 per cent. of tin do not greatly vary from 8.95, and that the specific gravities of castings of these alloys will be less than 8.95 according to their degrees of porosity. Riche gives figures showing the increase of density of sev-

eral alloys by tempering and compression. The specific gravity of an alloy of 94 copper, 6 tin, was increased from 8.541 to 8.939 by repeated tempering and rolling.

The specific gravity of pure copper, according to a large number of authorities quoted in "*Constants of Nature*," varies from 8.360 to 8.958, electrolytic, hammered, rolled, or pressed copper giving the highest figures and those which probably are the most nearly correct.

The specific gravity of No. 6 A as before stated is 8.943, and those of all the alloys containing between 25 and 38 per cent. of tin, which alloys are all very compact and homogeneous, are greater than 8.9 (reaching 8.97 at the latter percentage), both as determined in these experiments, and as determined by Calvert and Johnson. These results, therefore, tend to confirm the above statement that the specific gravities of all the alloys containing less than 25 per cent. of tin are nearly 8.95, and that a determination which gives a less figure reveals the porosity of the casting.

The specific gravities given in the above tables, as determined from pieces of the castings, are more valuable than if they were determined only from turnings, for the reason that they show the cause of imperfections in strength and other qualities, and indicate that the proper method of improving the strength is to increase the density. They also indicate that the lower the specific gravity of one of these alloys, which shows a certain definite strength, the greater increase may probably be given to that strength by any means which will cause the specific gravity to approach the fignre 8.95.

The several methods of increasing the specific gravities of these alloys and thereby increasing their strength yet remain to be experimented upon. It is well known that rolling, hammering, or pressing the porous and ductile metals increases the density. Casting under pressure has the same effect, as shown in the greater density of the bottom of a heavy gun casting than the top or the sinking head, and in a still more marked degree by experiments which have lately been made of casting under very heavy hydraulic pressure. It is probable also that temperature of pouring and rate of cooling have an important influence upon the density, and that the use of any fluxes which may remove occluded gases from the molten metals will be likely to increase it.

The maximum density of the series is given by the alloy No. 12 (62.31 copper, 37.35 tin, by analysis), the original mixture of which corresponds to the formula $Sn\ Cu_3$, and it is nearly approached by the alloy, No. 38 (62.42 copper, 37.48 tin). The figures are 8.970 and 8.956 respectively. The former is higher than is given by any authority quoted in "*Constants of Nature*" for any alloy of copper and tin. The specific gravity of the same alloy according to Calvert and Johnson is 8.954. Calvert and Johnson's maximum figure is 8.965, which was obtained with the alloy, $Sn\ Cu_5$ (72.90 copper, 27.10 tin). Bolley states that a large clock bell at Reichenhall, six hundred years old, has a specific gravity of 9.1, its composition being 76.20 copper, 23.80 tin. This figure is so much higher than that given by any other authority that it may be considered doubtful.

From the alloy No. 12 to the end of the series, or to pure tin, there is an almost perfectly regular decrease of specific gravity, that of tin being 7.293, which figure agrees with the results of several other authorities. From the regularity of this decrease of specific gravity, and from the fact that all the results between the alloy containing 62.31 copper, 37.35 tin, and pure tin agree closely with the figures given by other authorities for the specific gravities of the same alloys, as is plainly shown in the curves

of comparison of authorities (Plate XII), it appears that these alloys are much less apt to vary in their densities than those containing less than 25 per cent. of tin, and that they have but little, if any, porosity. It is therefore probable that their densities will not greatly vary under different methods of casting and rates of cooling.

It has been observed that the densities of the alloys containing less than 20 per cent. of tin have direct relation to their strengths, the strength being greater as the density is greater. This does not appear to be the case with the alloys containing more tin than the alloy of maximum density, and in these alloys there is a regular decrease of density, but a great irregularity in strength. It has also been noticed that different portions of the same bar vary considerably in strength, but have almost exactly the same density. The variations in strength, as before stated, seem to depend upon the rate of cooling, and possibly upon differences of pressure, causes which apparently have an important influence upon the crystallization, but not upon the density.

COMPARISON OF RESISTANCES.

By inspection of the curves of comparison of strength by transverse, tensile, torsional, and compressive stresses (Plate VII), it will be seen that the curves of tensile and torsional strengths agree very closely, the torsional curve being laid down to such a scale that one foot-pound of torsional moment is equivalent to 200 pounds of tensile strength. The curve of transverse strength is similar to those of tension and torsion (the scale being such that one pound modulus of rupture corresponds to one pound tensile strength), but the ordinates of the points of the curve representing most of the alloys are much greater than in the two latter curves.

The curve of compressive strength is very unlike either of the other curves. Being laid down to the same scale as that of tensile strength the ordinates of the curve are all much higher, showing that the compressive strengths per square inch of all the copper-tin alloys are much greater than their tensile strengths. The maximum compressive strength is reached by one of the brittle alloys, the tensile strength of which was not far from the minimum.

It appears, therefore, that the tensile and compressive strengths of the alloys are in no way related to each other; that the torsional strength is closely proportional to the tensile strength, and that the transverse strength may depend, in some degree, upon the compressive strength, as is indicated by the approach of some portions of the transverse curve to the compression curve, but it is much more nearly related to the tensile strength, as is shown by the general correspondence of the curve of transverse with that of tensile strength. The modulus of rupture, as obtained by the transverse tests, is in general a figure between those of tensile and compressive strengths per square inch, but there are a few exceptions in which it is larger than either.

From the curves of transverse, tensile, and torsional strengths it is seen that the strengths of the alloys at the copper end of the series increase rapidly with the addition of tin, till about 4 per cent. of tin is reached. The transverse strength continues regularly to increase to the maximum, till the alloy containing about 17½ per cent. of tin is reached, while the tensile and torsional strengths also increase, but very irregularly, to the same point. As this irregularity corresponds to the irregularity in the same portion of the curve of specific gravities, it is probably

due to porosity of the metal, and might possibly be removed by any means which would make the castings more compact.

The maximum point of the three curves is reached at the same point, viz, at the alloy containing 82.70 copper, 17.34 tin, the transverse strength, however, being very much greater at this point than the tensile or torsional strength.

From the point of maximum strength the three curves drop very rapidly to the alloys containing about 27.5 per cent. of tin, and then more slowly to 37.5 per cent., at which point the minimum or nearly the minimum strength of tin, by all three methods of test, is reached. The compression curve reaches its maximum between these points. The alloys of minimum strength are found from 3.75 per cent. tin to 52.5 per cent. tin; the observations being somewhat irregular between these points, making it difficult to state the exact minimum points of the curve, but all agreeing in showing great weakness. The absolute minimum is probably about 45 per cent. of tin.

From 52.5 per cent. of tin to about 77.5 per cent. tin there is a rather slow and irregular increase in strength to the point which has been called the second maximum, the curve of transverse strength at this point, as at the first maximum, rising much higher than the other two curves. The former, also, does not reach its second maximum at the same point as the two latter, but this may be accidental.

From 77.5 per cent. tin to the end of the series, or all tin, the strengths slowly and somewhat irregularly decrease, the second minimum being reached at the end of the curve. It will be noticed that the irregularity of the torsional curve is much less than those of the other curves, which is probably due to the fact that in the torsional tests the time occupied in making the tests was very uniform, and also that the torsional curve is made from the average results of usually four tests of each bar, while the tensile tests were but two in number from each bar, and the transverse tests but one.

One of the most important facts to be learned from the curves is that all the alloys containing more than 25 per cent. tin are practically worthless for all purposes where strength is required, the average strength of these alloys being only about one-sixth of the average of those containing less than 25 per cent. of tin.

COMPARISON OF DUCTILITY.

The ductility of the alloys is shown by the plate (No. IX) of curves of ductility by transverse, tensile, and tortional stresses. These three curves agree in showing that the ductility follows a very regular law, depending upon the composition.

The ductility in the tensile tests was determined by direct observations of the elongations of the pieces under tension. In the cases of the brittle alloys these elongations were such very small quantities that they could not be measured, and the curve, therefore, touches the axis of abscissas.

The ductility in the transverse tests was determined by the final deflections before breaking, and as this was always an appreciable quantity even with the brittle alloys, the curve is easily laid down, except in cases in which the bar bent without breaking. The curve, therefore, cuts the top of the plate in two points, thus indicating that the ductility by transverse stress without those points is indeterminate but very great.

The ductility by torsional tests is determined from the extension of the exterior fiber or line of particles in a torsion-piece one inch long, in parts of an inch, which is calculated from the angle of torsion given by

the autographic strain diagram. This gives a correct comparison of the relative ductility of all the pieces tested, whether very brittle or very ductile, and the comparative ductility is given in the figures in the table of summary of results. The maximum angle of torsion given in the summary is 556.75 degrees, which corresponds to an extension of 2.1975 inches of a line of particles, originally one inch long, on a cylinder $\frac{5}{8}$ inch in diameter, on the supposition that the diameter and length of the cylinder while being twisted remained unchanged. The minimum angle of torsion is 0.4 degree, which corresponds to an extension of only 0.000006 inch. The ductility of pure tin being therefore more than 200,000 times that of the most brittle alloy, they cannot both be represented in a curve drawn on the same scale, except when the lower portion of the curve practically coincides with the bottom line of the plate. The curve is therefore drawn so as to make it coincide with the curve of ductility by tensile tests.

Referring to the three curves, it will be seen that the alloys containing less than 12.5 per cent. of tin, and more than 87.5 per cent. of tin, are so ductile that bars of 22 inches in length bend to a deflection of more than $3\frac{1}{2}$ inches without breaking, and their comparative ductility is not, therefore, determined by this method of test. Bar No. 1, all copper, is an exception, but it was considered to be a defective bar. Bar No. 30, all copper, bent without breaking.

The comparative ductility of these alloys is plainly shown by the curves obtained from tensile and torsional tests. From both curves it appears that, beginning at pure copper, the ductility increases slightly with the addition of tin till from 2 to 4 per cent., between which limits the maximum ductility of the stronger alloys is reached. From this point there is a regular curve of decrease of ductility to 25 per cent. tin, at which point it becomes so small that both curves apparently touch the base line. The record of comparative ductility by tension is then entirely lost up to the alloy containing 75 per cent. tin, while that by torsion is lost in the curve, but can be traced from the figures in the table of summary of results. From these figures it is seen that the minimum ductility is reached at from 37.5 to 47.5 per cent. tin, which corresponds nearly to the minimum point of strength.

The curve of ductility by transverse strength, commencing at about 12.5 per cent. tin, shows a regular curvature tending toward the bottom of the plate, to about 35 per cent. tin, and from that point to 55 per cent. tin it is nearly horizontal, indicating a minimum at 45 per cent., thus agreeing with the result obtained from the torsional tests. From 55 per cent. tin there is a very regular curve upward to 87.5 per cent. tin, at which point the transverse curve is lost in consequence of the bars bending without breaking.

The curves of tensile and torsional ductility appear to rise from the bottom line at about 75 per cent. tin, and from that point to the end, or pure tin, there is a very regular increase, the regularity being much greater in the tests by torsion than in those by tension.

TOTAL RESILIENCE.

The resilience or amount of work done in breaking each of the alloys is shown by the figures in the table of summary of results under headings of transverse and torsional tests, and by the curves plotted from these figures.

The work done in breaking any specimen is measured in the same manner as mechanical work of any kind, that is, by the product of a

resistance into the distance through which the resistance acts. When the resistance is variable the work is the product of the mean resistance into that distance.

The work done in breaking a piece of metal by tensile stress is equal to the mean resistance multiplied by the total elongation; by transverse stress it is the mean resistance multiplied by the total deflection, and by torsional stress it is the mean resistance of the specimen as measured by the mean ordinate of the autographic strain diagram, expressed in foot-pounds of torsional moment, or pounds acting at the radius of one foot multiplied by the distance through which this moment is exerted as measured by the total abscissa of the diagram and reduced to feet traversed by the resistance.

The resilience under transverse stress has been calculated from the curves of deflections by transverse stress (Plates XVI, XVII), the area of the curve being directly proportional to the resilience, the ordinates representing resistances and the abscissas deflections. The results as given in the tables are reduced to foot-pounds of work. In the cases of the bars which bent to a deflection of more than $3\frac{1}{2}$ inches without breaking, the total resilience within the breaking point could not be determined, and the resilience within the limit of $3\frac{1}{2}$ inches deflection has been taken instead.

The torsional resilience has been calculated from the area of the autographic strain diagram in the manner above stated, the total resilience up to the breaking point being taken in each case and reduced to foot-pounds of work.

The resilience under tensile stress has not been determined, since the elongations of all the brittle pieces were not measured, and those of many of the ductile pieces were not determined with the same accuracy which characterized the transverse and torsional tests.

Referring to the plate of curves of resiliences (Plate X) it will be seen that the resilience bears a very close relation to the ductility, the curves of the two properties being nearly similar, except in those portions of the curves representing the ductile alloys, which bent without breaking under transverse stress, and of which the transverse resilience is taken only within a deflection of $3\frac{1}{2}$ inches, while the torsional resilience is taken to the point of rupture.

The maximum torsional resilience is given by bar No. 3 (96.06 copper, 3.76 tin), which was one of the most ductile of the stronger alloys. No. 33 (88.40 copper, 11.59 tin) gave the maximum transverse resilience within the deflection of $3\frac{1}{2}$ inches, on account of its being the strongest alloy which reached that deflection without breaking, but its total resilience is much less than those of the more ductile bars, which bent without breaking to deflections of more than 8 inches.

From the bar which gave the maximum total resilience of 599.96 foot-pounds there is a rapid decrease to No. 8 (76.64 copper, 23.24 tin), which had a resilience of only 3.72 foot-pounds. From No. 8 to No. 20 (35.85 copper, 73.80 tin) all of the bars, with one exception, show total resiliences by torsion of less than one foot-pound each, the minimum being only 0.08 foot-pounds, or only about $\frac{1}{7500}$ part of the maximum. These resiliences being so small compared with the maximum, the curve of resiliences (Plate III) between these points approaches the bottom line of the plate so closely that it apparently coincides with it. The figures for transverse resilience agree quite closely with those of torsional resilience between these points.

From bar No. 20 to No. 28 (0.32 copper, 99.46 tin) there is a gradual increase of the total resiliences to 125.99 foot-pounds, which is the "second

maximum" point of the curve. The bar of pure tin shows a somewhat less resilience, on account of its less strength, than No. 28, although it possessed a slightly greater ductility. The second maximum resilience by transverse stress within a deflection of 3½ inches is reached by No. 24 (11.49 copper, 88.47 tin), on account of its having the greatest strength of the bars containing a large amount of tin which bent without breaking. The transverse resiliences (within the deflection of 3½ inches) decrease to No. 29 (all tin), on account of the decrease of strength, while the total resiliences increase on account of the rapid increase of ductility.

LIMIT OF ELASTICITY.

The limit of elasticity has been defined as the point at which the distortion (either by tension, torsion, compression, or transverse stress) begins to increase in a greater ratio than the force which causes the distortion. It corresponds nearly with the point of first appreciable set, or permanent distortion. In the plotted curves of deflections and elongations and in the autographic diagrams of torsional stress it is the point at which the curve begins (usually suddenly) to change its direction and deflect toward the horizontal.

The plate of curves in which comparison is made of the transverse, torsional, and tensile strengths, also contains curves showing the limit of elasticity under each of the three kinds of tests. These have been plotted from the figures given in the tables of tests by tensile, transverse, and torsional stresses under each series. In the table of general summary of results (Table XIII) the elastic limits are represented for more convenient comparison by parts of the total strengths.

It will be seen that there is a similarity in the curves of limits of elasticity obtained from the three kinds of tests, and that they coincide with the curves of strength in the middle portion or that portion of the series containing the brittle alloys, and fall beneath them at the ends, the figures in the table of summary of results showing the elastic limit to be 100 per cent. of the total strength, and that of the more ductile alloys to be in some cases as small as 20 per cent. of the total strength, and to increase with the decrease of ductility.

There is a considerable difference between the figures representing the ratios of elastic limit to total strength of the ductile alloys as determined by the various methods of tests. In general the ratios obtained by the tensile tests is higher than that obtained by either the transverse or torsional tests, and the two latter more nearly agree.

Referring to the curves and to the figures giving the ratios of elastic limit to breaking load, it is seen that in the stronger alloys, those containing less than 17.5 per cent. of tin, the elastic limit under tensile stress is reached at from 50 to 68 per cent. of the breaking load, and under transverse and torsional stress at about 35 to 45 per cent. As the percentage of tin is increased beyond 17.5 per cent., the ratio of elastic limit to ultimate strength is increased, the alloy No. 8 (76.64 copper, 23.24 tin) giving results which showed the ratio to be 100 per cent., or that the elastic limit was not reached till fracture took place. The same result is given by all the alloys from No. 8 to No. 21 (38.37 copper, 61.32 tin). From No. 21 to pure tin, the elastic limit is reached before fracture, by transverse and torsional tests. In the tensile tests of the alloys containing between 62.5 and 82.5 per cent. of tin the position of the elastic limit is doubtful, but it is probable it was either not reached or only just reached before fracture took place. In these alloys

the ratios of elastic limit to ultimate strength appear much higher in tests by torsional than by transverse stress. The ductile alloys containing large percentages of tin, give ratios under torsional stress which gradually decrease as the percentage of tin increases, the decrease being nearly regular from 98.5 per cent. to 45.3 per cent., between the alloy of 27.5 copper, 72.5 tin, and pure tin. In the transverse tests the ratio is much more nearly constant, varying somewhat irregularly between the same compositions from 43.8 to 27.3 per cent.

MODULI OF ELASTICITY.

The moduli of elasticity were calculated from the deflections observed in the transverse tests. In the tables of the tests of each bar a large number of moduli of elasticity have been calculated for each test to show the change of this modulus at different parts of the test both within and beyond the elastic limit. In the summary of results by transverse tests, and in the table of general summary of results (Tables II, VIII, and XIII), the figures given are considered to be the most probable modulus of each bar within the elastic limit where the deflections are proportional to the applied loads. The curve (Plate XI) has been plotted from these figures. The figures and the curve show a great irregularity, but not greater than might be expected from metals of different compositions, when it is remembered that the modulus of elasticity of a single metal, wrought iron, has been found by various experiments to vary from 18,000,000 to 40,000,000.

Referring to the figures of moduli in the table of summaries (Table XIII) and to the curve plotted from them, it is seen that in the alloy containing less than 24 per cent. of tin, which includes all the stronger and more valuable alloys of the eleven figures of moduli of elasticity which are considered reliable observations, nine of them are between 13,300,000 and 15,000,000, the other two being 10,203,205 and 12,472,655. These figures sufficiently establish the moduli of elasticity by transverse stress of these alloys to be, as shown by the curve, about 14,000,000.

From 25 per cent. to 35 per cent. tin the modulus seems to be somewhat greater, the four observations next after those above mentioned varying from 14,896,691 to 16,387,041. From 35 to 75 per cent, there is a very great irregularity. This corresponds to the irregularity in strength and other properties as shown by all the tests, but is a much greater irregularity than of any other property. No. 11 (65.34 copper, 34.47 tin) gives a modulus of over 19,000,000, while No. 12 (62.31 copper, 37.35 tin) gives less than half as much. The latter, it will be remembered, was the alloy of greatest density. The two facts may in some way be connected. Bar No. 14 (original mixture, 51.8 copper, 48.2 tin) gives a modulus of only 5,174,546. This bar showed a very great degree of liquation, but its low modulus may be partially due to the fact of the bar being shorter than the standard length of 22 inches between supports. The figure was therefore rejected as unreliable, as were also those of all the short bars. It is remarkable that the other bar which showed very great liquation, No. 17 (original mixture, 41.74 copper, 58.26 tin), should give a modulus of over 23,000,000, the highest figure given by any alloy in either series.

From the alloys containing 70 per cent. tin, to pure tin the moduli again become a little more regular, but still varying between 11,520,262 and 6,771,517, the tendency being to decrease as the tin increases. Of the eleven figures of moduli of the alloys containing more than 80 per cent. tin, including the bar of pure tin, nine give moduli between 6,700,000

l 8,000,000, the other two being 8,613,200 and 10,403,101, thus tending establish the modulus of these alloys at about 7,500,000 to 8,000,000, a little more than half that of the stronger alloys containing less than per cent. of tin.

EXTRA BARS OF COPPER AND TIN.

During the progress of the experiments which have been described, number of bars of copper were made in the ingot-mold for the purpose being broken into small pieces to facilitate the weighing of the mixres for the alloys. Several of these bars were tested by transverse, nsile, torsional, and compressive stresses for the purpose of comparing em with the one selected as a standard. The records of all these tests e appended after the records of the tests of the alloys. The following bles give a summary of the results, including those of bars No. 1 and o. 30, which have already been given.

In addition to these, a test was made of an extra bar of Queensland tin, e record of which is also given. The ingot tin from which this bar as cast was furnished to the writer by Hon. Angus Mackay, commisoner from Queensland, Australia, to the Centennial Exhibition at hiladelphia, and was part of the Queensland exhibit. In the summary, s record is compared with that of the Banca tin, bar No. 29.

SUMMARY OF RESULTS OF TESTS OF BARS OF COPPER AND TIN.

TABLE XIV.—TRANSVERSE TESTS.

Material.	Length between supports.	Breadth b.	Depth d.	Breaking load P.	Modulus of rupture, $R=\frac{3Pl}{2bd^2}$	Total deflection Δ.	Limit of elasticity.		Modulus of elasticity.	Remarks.
							Load.	Parts of breaking load.		
	Ins	*Ins*	*Ins.*	*Pds*		*Ins.*				
L. S. copper ...	22	0.994	1.010	650	21,251	2.306	225	.346	13,986,605	Broke; very defective.
...do	22	0.990	0.980	860	29,848	3.+	140	.140	10,203,205	Cast at very high temperature; bent.
...do	22	1.000	1.000	860	28,380	1.38	350	.407	10,443,980	Cast at high temperature; bent; defective.
...do	22	1.000	1.000	643	21,219	1.23+	140	.218	11,788,856	Cast at lower temperature than No. 53; bent.
...do	22	0.985	0.970	860	30,621	3.+	240	.279	10,540,763	Cast at high temperature; bent.
...do	22	0.972	0.955	640	23,824	3.51+	180	.281	9,339,672	Cast at lower temperature than No. 55; bent.
... do	22	1.010	1.010	820	26,271	1.77+	200	.244	9,511,283	Bent.
Mean of 7 bars..	...	.....	.....	762	25,916	.....	...	.274	10,830,623	
Queensland tin..	22	1.038	1.023	150	4,559	1.+	40	.267	5,635,593	Bent.
Banca tin	22	0.993	1.002	110	3,740	3.+	30	.273	6,734,838	Bent.
Mean of 2 bars.	...	.....	.....	130	4,150	.....	....	.270	6,185,210	

TABLE XV.—TENSILE TESTS.

Number.	Material.	Diameter of sections.		Total elongation—parts of original length.	Tenacity per square inch of—		Elastic limit.		Remarks.
		Original.	Fracture.		Original section.	Fractured section.	Pounds per square inch.	Parts of breaking load.	
		Ins.	*Ins.*		*Pounds.*	*Pounds.*			
1 A	L. S. copper	.798	0.790	.0060	14,180	14,464	12,000	.....	Very defective.
1 B	do	.798	0.742	.0033	11,340	11,509	10,000	.....	Do.
Mean		.798	0.766	.0047	12,760	12,987	11,000	.862	
30 A	L. S. copper	.798	0.725	.0752	29,200	34,790	14,000	.....	
30 B	do	.798	0.740	.0541	26,400	30,201	14,000	.....	
Mean		.789	0.733	.0647	27,800	32,496	14,000	.518	
51 A	L. S. copper	.798	0.775	.0261	14,540	15,412	9,840	.....	Fluxed with fluor-spar.
51 B	do	.798	0.763	.0743	20,440	22,353	10,000	.....	Do.
Mean		.798	0.769	.0502	17,490	18,883	9,920	.567	
52 A	L. S. copper	.798	0.775	.0160	16,940	17,956	9,800	.....	
52 B	do	.798	0.711	.0916	21,600	27,204	11,200	.....	
Mean		.798	0.743	.0538	19,270	22,580	10,500	.465	
53 A	L. S. copper	.798	0.780	.0163	18,800	19,763	12,860	.681	Very defective.
53 B	do	.798	.....	.....	9,200	.....	.....	.....	Do.
Mean		.798	.....	.....	14,000	.....	.....	.....	
57 A	L. S. copper	.798	0.738	.0934	26,000	30,398	11,000	.....	
57 B	do	.798	0.724	.0717	29,820	36,217	12,000	.....	
Mean		.798	0.731	.0826	27,910	33,308	11,500	.412	
	Mean of all	.....	.....	.0454	19,872	23,336	11,620	.584	
58 A	Queensland tin	.798	0.580	.....	2,000	.....	.....	.....	Slow test.
58 B	do	.798	0.542	.....	3,520	.....	.....	.....	Rapid test.
Mean		.798	0.561	.....	2,760	.....	.....	.....	
29 A	Banca tin	.798	0.400	.2833	2,800	.....	.....	.....	Slow test.
29 B	do	.798	0.300	.4269	4,200	.....	2,000	.476	Rapid test.
Mean		.798	0.395	.3551	3,500	.....	.....	.....	
	Mean of all	.....	.....	.3551	3,130	.....	.....	.....	

TABLE XVI.—TORSIONAL TESTS.

Averages of the Results calculated from the Autographic Strain Diagrams.

Number.	Material.	Area of diagram.	Angle of torsion.	Ordinates of diagram.		Torsional moment.		Extension of exterior fiber.	Resilience.	No. of pieces averaged.	Remarks.
				Maximum.	At elastic limit.	Maximum.	At elastic limit.				
		Sq. ins.	*Degrees*	*Ins.*	*Ins.*	*Ft. lbs.*	*Ft. lbs.*		*Ft. lbs.*		
1	L. S. copper	1.30	40.5	0.47	0.19	65.66	33.17	0.0255	37.71	3	Defective.
30	do	17.61	153.0	1.38	0.46	143.24	50.63	0.3084	320.35	4	
51	do	10.99	136.1	1.05	0.36	109.27	42.81	0.2486	201.95	4	
52	do	12.51	154.7	1.07	0.28	119.97	34.44	0.3159	285.75	3	
53	do	3.92	52.0	0.90	0.38	94.73	41.80	0.0434	90.29	4	Defective.
57	do	9.23	111.2	0.95	0.35	93.77	39.28	0.1790	170.12	4	
	Mean of all	9.26	107.9	1.09	0.34	105.44	40.35	0.1868	184.36	....	
58	Queensland tin	42.78	691.0	0.73	0.22	13.15	4.36	2.9029	208.48	3	
29	Banca tin	21.26	556.8	0.48	0.13	12.75	5.78	2.1975	105.45	4	
	Mean	32.02	623.9	0.61	0.18	12.95	5.07	2.5502	156.97	....	

BLE XVII.—AVERAGE RESULTS OF TESTS OF COPPER, REJECTING THOSE MARKED DEFECTIVE, AND AVERAGE OF ALL TESTS OF TIN.

	Transverse tests.				Tensile tests.				Torsional tests.				
	Breaking load.	Modulus of rupture.	Elastic limit—parts of breaking load.	Modulus of elasticity.	Elongation—parts of original length.	Tenacity per square inch of— Original section.	Tenacity per square inch of— Fractured section.	Elastic limit—parts of breaking load.	Maximum torsional moment.	Torsional moment at elastic limit.	Elastic limit—parts of breaking load.	Extension of exterior fiber.	Resilience.
pper.....	765	26,357	.232	10,076,756	.0628	23,118	26,817	.491	118.06	41.79	.354	0.2630	244.54
.....	130	4,150	.270	6,185,210	.3551	3,130	.....	.476	12.95	5.07	.392	2.5502	156.97

TABLE XVIII.—ANALYSES OF TURNINGS FROM FOUR BARS OF COPPER.

	No. 1.	No. 30.	No. 53.	No. 57.
tallic silver	0.035	0.014	0.015	0.063
tallic iron	0.020	0.014	0.035	0.014
tallic zinc	0.014	0.057	0.016	None.
tallic lead	Trace.	Trace.	None.	Trace.
tallic bismuth	None	None	None	None.
tallic arsenic	None	None	None	None.
tallic antimony	None	None	None	None.
boxide of copper	12.086	3.580	6.730	1.620
tallic copper	87.900	96.330	93.200	98.330
oluble matter	.....	.....	.....	0.005
rbon	None	.....	.....	.....
	100.055	99.995	99.996	100.032

TABLE XIX.—ANALYSIS OF "QUEENSLAND TIN."

	Per cent.		Per cent
ad	0.165	Antimony	none.
n	0.035	Bismuth	"
nganese	0.006	Nickel	"
senic	trace.	Cobalt	"
pper	none.	Tungsten	"
nc	"	Molybdenum	"

It will be observed that there is a very considerable difference both in rength and ductility of the several bars which were cast from the same etal, and under nearly the same conditions. The causes of this differ- ce have not been ascertained, as the bars were merely cast incidentally ring the mixing of the alloys, and no attempt was made to learn ex- tly the conditions under which each casting was made. A special in- sigation would be needed before it could be definitely asserted what as the cause of the good or the bad qualities of any particular bar, or how e defects of any of them might be remedied.

The analyses of bars No. 1, No. 30, No. 53, and No. 57 show that the ittleness is an accompaniment of a large percentage of suboxide of pper in the bar, the presence of which is probably the proximate cause the brittleness. The analysis of No. 1 showed it to contain 12.086 per nt. suboxide of copper; No. 30, 3.580 per cent.; No. 53, 6.730 per cent.; d No. 57, 1.620 per cent.

No. 1 and No. 53 broke under transverse stress, the former with a de-

flection of 2.306 inches, the latter with 1.38 inches. All the others bent without breaking. No. 1 was recast several times, which might have been the cause of its being defective, but No. 53 was nearly as defective, while it was cast only once. No. 53 and No. 54 were cast at the same time, the former being at the higher temperature, as judged by the founder from its appearance when poured. No. 55 and No. 56 were cast subsequently, and their relative temperatures were determined in the manner described in treating of the casting of the second series of the alloys, viz, by pouring a portion of the molten metal into water and noting the rise of temperature of a given weight of water and the weight of metal poured. The following are the data of these temperature tests:

No.	Weight of water.	Weight of metal.	Temperature of water.			Assumed specific heat.	Calculated relative temperature.	
			Initial.	Final.	Increase.		Fahrenheit.	Centigrade.
	Grammes.	*Grammes.*	*Deg. Fahr.*	*Deg. Fahr.*	*Deg. Fahr.*		*Degrees.*	*Degrees.*
55	5145.6	579.6	46	79	33	0.09515	4145.93	1858.30
56	5145.6	325.6	51¼	73½	22	0.09515	4927.01	2175.56

No. 56 was supposed to have been cast at least as hot as No. 53, but the test showed the former to be a very good bar, while the latter was a very bad one. The difference in temperatures of casting, therefore, does not seem sufficient to explain the difference in properties of the casting.

No. 30 was cast at an extremely high temperature, much higher than either of the other bars, being at a dazzling white heat. On pouring a small portion into water in attempting to obtain the relative temperature, a severe explosion took place, and this was repeated every time that even a small drop of the molten metal touched the water. The cold ingot mold was then filled with this very hot metal. After the metal remaining in the crucible had stood for several minutes and had cooled considerably, it could be poured into water without causing the slightest explosion.

It might be supposed that the result of this casting at a very high temperature would be to make bar No. 30 a bad bar, as this seems to be indicated by bars No. 53 and No. 54, and also by the experiments of Major Wade on gun-metal. The result, however, showed the contrary, as it proved to be equal to any of the bars which were cast.

No. 57 was cast apparently at a medium temperature, much lower than No. 30, but it is not known how its temperature compared with that of others. The test showed it to be nearly as good a bar as No. 30.

The tensile and torsional tests indicate the qualities of the different bars even more plainly than the transverse tests. The tables explain themselves sufficiently.

It will be observed that the tensile tests show a much greater difference between the bars than do the transverse. The reason of this is, no doubt, that the tensile test-piece always breaks at its weakest section, no one part of the cylindrical portion of the piece being subjected to a greater stress than the others, while in the transverse test the middle section is the dangerous section, or position of maximum strain, and the bar will usually break in the middle, although other portions may be weaker. In defective bars, therefore, the tensile test usually reveals the defects more plainly than the transverse test, especially if these defects are unevenly distributed.

The cause and method of prevention of the defects in cast copper yet main to be investigated.

The bar of Queensland tin proved to be a very good bar, showing a mewhat greater strength by transverse and torsional tests than the r of Banca tin, but a less strength by tension. The transverse rength is probably higher both on account of the different methods of st, the bar of Banca tin being tested by dead loads and that of Queens- nd tin by the platform-scale apparatus, and on account of a flaw in e middle of the Banca-tin bar.

The effect of slow and rapid test is shown by both bars in the tensile test. ıe average tenacity of all the pieces tested is given as 3,130 pounds per uare inch, but it is probable that all the pieces would have broken at low as 2,000 pounds if the test had been of long duration, say one our, or as high as 4,000 pounds if each test had been made in, say, five inutes.

The effect of time is also shown in the autographic strain diagrams ıd in the records calculated from them.

The Queensland tin showed an extraordinary ductility in the torsional sts, one of the pieces twisting through an angle of 818 degrees, or more ıan 2¼ turns before breaking. This represents an elongation of a line particles parallel to the axis on the surface of the cylindrical portion the test piece from one inch to 4.57 inches.

COMPARISON OF AUTHORITIES.

The following table gives a list of about 140 different alloys of copper nd tin, including all those which have been described in this report, ogether with a large number collated from standard authorities, giving ome of their mechanical and physical properties. The results obtained y experimenters, whose investigations were sufficiently complete to llow of such a comparison, are shown graphically in Plates XII, XIII, IV, XV.

LIST OF AUTHORITIES.

Abbreviations.

B.—Bolley. *Essais et Recherches Chimiques.* Paris, 1860, pp. 345, 348.
Cr.—Crookewit. *Erdmann's Journal,* 1848, vol. 45, pp 87–93.
C. J.—Calvert and Johnson. Specific Gravities, *Phil Mag.*, 1859, vol. 18, pp. 354-359; Hardness, *Phil. ag.*, 1859, vol. 17, pp. 114–121; Heat Conductivity, *Phil. Trans.*, 1858, pp. 349–368.
De.—S. B. Dean. *Ordnance Notes.* No. XL, Washington, 1875.
La.—Laborde. *Dingler's Journal,* 1855, vol. 135, p. 269.
Ml.—Mallet. *Phil. Mag.*, 1842, vol. 21, pp. 66–68.
Ms.—Matthiessen. *Phil. Trans.*, 1860, p. 161; *ibid.*, 1864, pp. 167–200.
Mar.—Marchand and Scheerer. *Journal für Praktische Chemie,* vol. 27, p. 193 (Clark's "*Constants of ture*").
Mus.—Muschenbroek. *Ure's Dictionary,* article "Alloy."
Rl.—Riche. *Annales de Chimie,* 1873, vol. 30, pp. 351–419.
U. S. B.—*Report of Committee on Metallic Alloys, of United States Board appointed to test Iron, Steel, &c.*
Th.—Thomas Thomson. *Ann. de Chimie,* 1814, vol. 89, pp. 46–54.
W.—Watt's *Dictionary of Chemistry* (compiled from several authorities).
Wa.—Major Wade, United States Army. *Report on Experiments on Metals for Cannon,* Phila., 1856.
We.—Weidemann. *Phil. Mag*, 1860, vol. 19, pp. 243, 244.

TABLE XX.—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
1	.....	100	0	.....	.....	{ 8.791*a* 8.874*b*	Copper red	Fibrous ...	27,800	....	30.8	.....	.....	.....	.....	.....	U. S. B.	{ *a* Specific gravity of bar. *b* Specific gravity of turnings from ingot.
2	.....	100.00	0.00	.....	.....	8.667	Tile red	Earthy....	55,104	1	.....	10	2	16	.....	.....	M	
3	.....	100.00	0.00	.....	.....	8.921	.....	.....	.....	....	.....	.....	.....	.....	.....	93.16	Ma.	
4	.....	100.00	0.00	.....	.....	.....	.....	.....	.....	....	.....	301	.....	.....	81.1	.....	C. J.	
5	.....	100.00	0.00	.....	.....	8.794	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Cr.	
6	.....	100.00	0.00	.....	.....	8.921	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Mar.	Cast copper.
7	.....	100.00	0.00	.....	.....	8.952	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Mar.	Sheet copper.
8	.....	100.00	0.00	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	73.6	79.3	We.	
9	.....	100.00	0.00	.....	.....	8.672	.....	.....	24,252	....	.....	.....	.....	.....	.....	.....	Na.	Mean of 9 samples.
10	.....	98.59	1.41	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	62.46	Ma.	
11	$Sn Cu_{99}$ ...	98.10	1.90	97.89	1.90	8.564	Red	Vesicular	.....	....	100.1	.....	.....	.....	.....	.....	U. S. B.	Defective bar.
12	.....	98.04	1.96	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	B.	Can be forged like copper.
13	.....	98.00	2.00	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	La.	Ramrods for guns.
14	.....	97.50	2.50	.....	.....	8.511	Red	Vesicular	.....	....	.....	.....	.....	.....	.....	.....	U. S. B.	Defective bar.
15	.....	96.97	3.03	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	W.	Resists action of hydrochloric acid.
16	$Sn Cu_{28}$ ...	96.27	3.73	96.06	3.76	8.649	Reddish yellow	Vesicular .	32,000	....	70.3	.....	.....	.....	.....	.....	U. S. B.	
17	.....	96.00	4.00	.....	.....	8.947	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Ri.	Annealed and compressed.
18	.....	95.00	5.03	.....	.....	.....	Golden yellow	.....	.....	....	.....	.....	.....	.....	.....	.....	W.	Hard malleable.
19	.....	94.10	5.90	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	B.	Pieces of machines.
20	.....	94.00	6.00	.....	.....	8.939	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Ri.	Specific gravity after repeated tempering.
21	.....	93.98	6.02	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	19.68	Ma.	
22	$Sn Cu_{25}$ ...	93.17	6.83	.....	.....	8.820	.....	.....	.....	....	.....	602.08	.....	.....	.....	.....	C. J.	
23	$Sn Cu_{24}$ ...	92.80	7.20	.....	.....	8.694	Reddish yellow	Vesicular .	23,540	....	21.9	.....	.....	.....	.....	.....	U. S. B.	
24	.....	92.50	7.50	.....	.....	8.684	....do	....do	27,900	....	43.2	.....	.....	.....	.....	.....	U. S. B.	
25	.....	92.00	8.00	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	B.	Bronze for medals.
26	.....	91.75	8.25	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	W.	Shows separation of metals when examined with a lens.
																	B.	English ordnance.
																	B.	Ordnance-metal.

37	.....	90.00	10.00	.....	.....	8.875	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	De.	bronze.
38	.....	90.00	10.00	.....	.....	8.935	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	After repeated compression. Railroad-car bearings.
39	.....	90.00	10.00	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Ordnance-metal.
40	.....	89.30	10.70	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Small bar cast in iron mold.
41	.....	89.29	10.71	.....	.....	8.953	.....	.....	37,688	...	.....	.....	.....	.....	.....	.....	Wa.	Small bar cast in clay mold.
42	.....	89.29	10.71	.....	.....	8.313	.....	.....	25,783	...	.....	.....	.....	.....	.....	.....	Wa.	Mean of 12 gun-heads.
43	.....	89.29	10.71	.....	.....	8.353	.....	.....	26,011	...	.....	.....	.....	.....	.....	.....	Wa.	Ordnance-metal.
44	.....	89.23	10.77	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	
45	$Sn Cu_{15}$ ...	89.00	11.00	.....	.....	8.84	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
46	$Sn Cu_{15}$ ...	88.97	11.03	.....	.....	8.825	.....	.....	.....	...	.....	772.92	.....	.....	.....	.....	C. J.	Mean of 83 gun-heads.
47	.....	88.89	11.11	.....	.....	8.523	.....	.....	29,655	...	.....	.....	.....	.....	.....	.....	Wa.	
48	.....	88.39	11.61	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	12.10	Ma.	Gun-metal.
49	.....	88.00	12.00	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	La.	
50	.....	87.65	12.35	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	10.15	Ma.	
51	.....	87.50	12.50	.....	.....	8.648	Grayish yellow	Earthy....	31,100	..	7.3	.....	.....	.....	.....	.....	U. S. B.	Regulator Belgian locomotive.
52	.....	86.80	12.40	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	W.	
53	$Sn Cu_{12}$ ...	86.57	13.43	87.15	12.73	8.681*a* 8.943*b*	Mottled white and yellow	Fine vesic.	29,430	....	13.9	.....	.....	.....	.....	.....	U. S. B.	*a* Specific gravity of bar. *b* Specific gravity of fine turnings.
54	.....	86.21	13.79	.....	.....	8.87	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	W.	Densest of all alloys! (Riche.)
55	.....	86.00	14.00	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	W.	Axle-tree bed. Seraing locomotive.
56	.....	85.71	14.29	.....	.....	.....	.....	.....	44,071	...	.....	.....	.....	.....	.....	.....	Mus.	
57	.....	85.09	14.91	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	8.82	Ma.	
58	$Sn Cu_{10}$ ...	84.33	15.67	.....	.....	8.87	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
59	.....	84.39	15.68	.....	.....	8.832	.....	.....	.....	...	.....	916.66	.....	.....	.....	.....	C. J.	
60	.....	84.29	15.71	.....	.....	8.561	Reddish yellow, 1.	Fine cryst.	36,064	2	.....	8	6	15	.....	.....	Mi.	
61	.....	84.00	16.00	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Carriage-wheel boxes.
62	.....	83.30	16.70	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Jewelers' punches.
63	$Sn Cu_9$	82.81	17.19	.....	.....	8.462	Reddish yellow, 2.	Fine cryst.	34,048	3	.....	5	7	14	.....	.....	Mi.	
64	.....	82.50	17.50	.....	.....	8.792	Reddish gray .	Fine cryst	36,200	....	0.32	.....	.....	.....	.....	.....	U. S. B.	Strongest of series.
65	.....	82.00	18.00	.....	.....	8.927	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	R.	Annealed and tempered.
66	$Sn Cu_8$	81.15	18.85	.....	.....	8.86	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
67	$Sn Cu_8$	81.10	18.90	.....	.....	8.459	Yellowish red, 2.	Fine cryst	39,648	4	.....	4	10	13	.....	.....	Mi.	
68	.....	.....	.....	80.43	19.57	8.953	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Th.	Chinese gong.

TABLE XX.—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES—Continued.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson.)	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver=100.	Conductivity for electricity, silver=100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
69	.....	80.00	20.00	.....	.....	8.7	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Bells of Reichenhall, 300 years old.
70	.....	80.00	20.00	.....	.....	.....	.....	.....	35,759	...	.....	.....	.....	.....	.....	.....	Mus.	
71	.....	80.00	20.00	.....	.....	8.870	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	Annealed and tempered.
72	.....	80.00	20.00	.....	.....	8.955	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	After repeated compression.
73	.....	80.00	20.00	80.95	18.84	8.740	Reddish gray	Fine gran	32,980	...	0.40	.....	.....	.....	.....	.....	U. S. B.	
74	.....	79.20	20.80	.....	.....	8.927	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	Annealed and tempered.
75	$SnCu_7$	79.02	20.98	.....	.....	8.90	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
76	$SnCu_7$	78.97	21.03	.....	.....	8.728	Yellowish red, l.	Vitr.conch.	30,464	5	.....	3	11	12	.....	.....	Mi.	
77	.....	78.00	22.00	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Best bell-metal.
78	.....	77.50	22.50	.....	.....	8.917	Pinkish gray..	Fine gran	24,650	...	0.03	.....	.....	.....	.....	.....	U. S. B.	
79	$SnCu_6$	76.32	23.68	76.64	23.24	8.565	.....	Smooth ...	22,010	...	0.02	.....	.....	.....	.....	.....	U. S. B.	
80	$SnCu_6$	76.31	23.69	.....	.....	8.91	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
81	$SnCu_6$	76.29	23.71	.....	.....	8.750	Bluish red ...	Vitreous ..	21,728	0	.....	2	12	11	.....	.....	Mi.	
82	.....	76.20	23.80	.....	.....	9.1(?)	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Church bell in Reichenhall, 600 years old.
83	.....	75.20	24.80	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Swiss clock bells, brittle.
84	.....	75.00	25.00	.....	.....	8.879	Reddish white	.....	.....	...	.....	.....	.....	.....	.....	.....	W.	
85	$SnCu_5$	72.91	27.09	.....	.....	8.87	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
86	$SnCu_5$	72.90	27.10	.....	.....	8.965	.....	.....	.....	...	.....	Broke	.....	.....	20.7	.....	C. J.	
87	$SnCu_5$	72.80	27.20	.....	.....	8.575	Bluish red ...	Conchoidal	10,976	0	.....	1	13	10	.....	.....	Mi.	
88	.....	72.50	27.50	.....	.....	8.925	Reddish white	Conchoidal	6,493	...	0.003	.....	.....	.....	.....	.....	U. S. B.	
89	.....	70.00	30.00	69.84	29.89	8.932	White	Conchoidal	5,585	...	0.008	.....	.....	.....	.....	.....	U. S. B.	
90	.....	68.82	31.18	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Mirror of telescope.
91	$SnCu_4$	68.28	31.72	.....	.....	8.80	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	Ri.	
92	$SnCu_4$	68.27	31.73	.....	.....	8.948	.....	.....	.....	...	.....	Broke	.....	.....	15.5	.....	C. J.	
93	$SnCu_4$	68.25	31.75	68.58	31.26	8.938	White	Conchoidal	1,620	...	.....	.....	.....	.....	.....	.....	U. S. B.	
94	$SnCu_4$	68.21	31.79	.....	.....	8.400	Ash gray	Conchoidal	1,568	0	.....	6	14	9	.....	.....	Mi.	
95	.....	68.21	31.70	.....	.....	.....	.....	.....	.....	...	.....	.....	.....	.....	.....	.....	B.	Mirror metal.
96	.....	67.50	32.50	.....	.....	8.907	White	Conchoidal	2,536	...	0.009	.....	.....	.....	.....	.....	U. S. B.	
97	.....	66.67	33.33	.....	.....	.....	Steel gray ...	.....	.....	...	.....	.....	.....	.....	.....	.....	W.	Hard, uniform.
98	.....	66.67	33.33	.....	.....	.....	.....	.....	1,017	...	.....	.....	.....	.....	.....	.....	Mus.	
99	.....	65.00	35.00	65.34	34.47	8.947	Bluish gray ...	.....	2,201	...	0.002	.....	.....	.....	.....	.....	U. S. B.	

103	$Sn Cu_2$	64.71	35.29			8.910	Dark gray	Rough, stony.	688		0.003						U. S. B.	Greatest density, weakest.
104	$Sn Cu_3$	61.69	38.31			8.539	Dark gray	Tabular cryst.	1,120	0		7	16	8			Mi.	
105		60.00	40.00														B.	White bell-metal.
106		57.50	42.50			8.781	Light gray	Stony	1,377		0.001						U. S. B.	
107	$Sn_5 Cu_{12}$	56.32	43.68	56.70	43.17	8.682	do	do	1,455		0.003						U. S. B.	
108		52.50	47.50			8.643	do	do			0.001						U. S. B.	Weakest under tranverse stress.
109	$Sn Cu_2$	51.84	48.16			8.57											Ri.	
110	$Sn Cu_2$					8.512											Cr.	
111	$Sn Cu_2$	51.83	48.17			8.533						Broke			42.8		C. J.	
112	$Sn Cu_2$	51.80	48.20	51.62	48.09	8.560	Light gray		2,555		0.003						U. S. B.	Remarkable for liquation.
113	$Sn Cu_2$	51.75	48.25			8.416	Grayish white.	Vit. conch.	3,898	0		9	15	7			Mi.	
114		50.00	50.00						745								Mus.	
115		50.00	50.00			8.79	Bluish white										W.	Very slightly malleable.
116	$Sn_7 Cu_8$	47.95	52.05	47.61	52.14	8.442	Grayish white.	Fine grain.	1,525		0.003						U. S. B.	
117		47.50	52.50			8.446	do	Cry tal	2,407		0.003						U. S. B.	
118	$Sn_2 Cu_3$	44.67	55.33			8.30											Ri.	
119	$Sn_3 Cu_5$	44.63	55.37	44.52	55.28	8.312	Grayish white.	Crystal	3,010		0.003						U. S. B.	
120		42.50	57.50			8.437	do	do	2,098		0.006						U. S. B.	
121	$Sn_3 Cu_4$	41.74	58.26	42.38	57.30	8.302	do	do	3,910		0.007						U. S. B.	
122		40.00	60.00														B.	White bell-metal.
123	$Sn_5 Cu_6$	39.20	60.80	38.37	61.32	8.182	Grayish white.	Crystal	2,820		0.005						U. S. B.	
124		37.50	62.50			8.101	do	do	2,400		0.004						U. S. B.	
125	Sn Cu	34.99	65.01			8.12											Ri.	
126	Sn Cu	34.98	65.02			7.992						Broke			41.5		C. J.	
127	Sn Cu					8.072											Cr.	
128	Sn Cu	34.95	65.05	34.23	65.80	8.013	Grayish white.	Crystal	3,371		0.005						U. S. B.	
129	Sn Cu	34.92	65.08			8.056	do	Tab. cryst.	3,136	0		11	9	6			Mi.	
130		33.33	66.67				White										W.	Brittle; uniform.
131		32.50	67.50			7.931	Grayish white.	Crystal	2,322		0.014						U. S. B.	
132	$Sn_4 Cu_9$	28.72	71.28	25.85	73.80	7.948	do	do	1,648		0.011						T.	
133		27.50	72.50			7.915	do	do	4,380		0.018						T.	
134		25.00	75.00			7.813	Bluish white	do									W.	
135	$Sn_3 Cu_{13}$	24.38	75.62	23.35	76.20	7.835	Grayish white.	Fine cryst.	6,775		0.03						T.	
136		22.50	77.50			7.774	do	do	5,000		0.12						T.	
137		21.74	78.26	21.28	77.63	7.53	Whitish										W.	Yellow, greenish white, shining.
138	$Sn_2 Cu$	21.21	78.79			7.738						135.42			43.1		C. J.	
139	$Sn_2 Cu$	21.21	78.79			7.74											Ri.	
140	$Sn_2 Cu$	21.18	78.82	20.25	79.63	7.770	Grayish white.	Crystal	4,337		0.06						T.	
141	$Sn_2 Cu$	21.15	78.85			7.387	do	Coarse crystal.	8,736	0		12	8	5			Mi.	
142	$Sn_3 Cu_2$	17.68	82.32			7.652											Cr.	
143		17.50	82.50			7.690	Grayish white.	Crystal	2,816		0.20						T.	
144		16.40	83.60													12.76	Ma.	
145	$Sn_3 Cu$	15.21	84.79			7.53											Ri.	

TABLE XX.—PROPERTIES OF THE ALLOYS OF COPPER AND TIN.

COMPARISON OF SEVERAL AUTHORITIES—Continued.

Number.	Atomic formula.	Composition of original mixture.		Composition by analysis.		Specific gravity.	Color.	Fracture.	Tenacity, pounds per square inch.	Order of ductility (Mallet).	Relative ductility (Thurston).	Hardness (Mallet, and Calvert and Johnson).	Order of malleability (Mallet).	Order of fusibility (Mallet).	Conductivity for heat, silver = 100.	Conductivity for electricity, silver = 100.	Authority.	Remarks.
		Cu.	Sn.	Cu.	Sn.													
146	Sn_3Cu	15.21	84.79	.....	.....	7.606	.....	.....	.....	....	.....	104.17	.....	.....	42.3	.....	C. J.	
147	Sn_3Cu	15.19	84.81	15.08	84.62	7.657	Grayish white.	Crystal ...	6,520	...	0.92	.....	.....	.....	.....	.....	T.	
148	Sn_3Cu	15.17	84.83	.....	.....	7.447	...do	Coarse crystal.	6,944	0	.....	13	15	4	.....	.....	Ml.	
149	.....	12.50	87.50	.....	.....	7.543	...do	Crystal ...	3,798	....	4.71	.....	.....	.....	.....	.....	T.	
150	Sn_4Cu	11.86	88.14	.....	.....	7.558	.....	.....	.....	....	.....	95.81	.....	.....	40.6	.....	C. J.	
151	Sn_4Cu	11.84	88.16	11.49	88.47	7.552	Grayish white.	Crystal ...	6,380	...	7.08	.....	.....	.....	.....	.....	T.	
152	Sn_4Cu	11.84	88.16	.....	.....	7.50	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Ri.	
153	Sn_4Cu	11.82	88.18	.....	.....	7.472	Grayish white.	Coarse crystal.	6,944	8	.....	14	4	3	.....	.....	Ml.	
154	Sn_5Cu	9.73	90.27	.....	.....	7.517	.....	.....	.....	....	.....	83.33	.....	.....	39.6	.....	C. J.	
155	Sn_5Cu	9.73	90.27	.....	.....	7.52	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Ri.	
156	Sn_5Cu	9.70	90.30	8.57	91.39	7.487	Grayish white.	Granular .	6,450	....	23.47	.....	.....	.....	.....	.....	T.	
157	Sn_5Cu	9.68	90.32	.....	.....	7.442	...do	Earthy ...	3,360	6	.....	15	3	2	.....	.....	Ml.	
158	.....	9.09	90.91	.....	.....	7.472	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	W.	Slightly malleable.
159	.....	7.50	92.50	.....	.....	7.417	Grayish white.	Granular .	6,096	....	40.06	.....	.....	.....	.....	.....	U. S. B.	
160	.....	6.43	93.57	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	.....	12.03	Ma.	
161	$Sn_{12}Cu$	4.29	95.71	3.72	96.31	7.360	Grayish white.	Granular .	4,780	....	56.77	.....	.....	.....	.....	.....	U. S. B.	
162	.....	2.50	97.50	.....	.....	7.342	...do	Fibrous...	5,600	....	121.9	.....	.....	.....	.....	.....	U. S. B.	
163	$Sn_{48}Cu$	1.11	98.89	0.74	99.02	7.305	...do	...do	3,650	....	133.9	.....	.....	.....	.....	.....	U. S. B.	
164	$Sn_{96}Cu$	0.56	99.44	0.32	99.46	7.299	...do	...do	4,475	....	208.8	.....	.....	.....	.....	.....	U. S. B	
165	Sn	0	100	.....	.....	7.293	...do	...do	3,500	....	219.8	.....	.....	.....	.....	.....	U. S. B.	
166	.....	0	100	.....	.....	7.291	White	...do	6,040	7	.....	16	1	1	.....	.....	Ml.	
167	.....	0	100	.....	.....	7.297	.....	.....	2,122	....	.....	.....	.....	.....	.....	.....	Wa.	
168	.....	0	100	.....	.....	7.294	.....	.....	.....	....	.....	.....	.....	.....	.....	11.45	Ma.	
169	.....	0	100	.....	.....	7.305	.....	.....	.....	....	.....	.....	.....	.....	.....	.....	Cr.	
170	.....	0	100	.....	.....	.....	.....	.....	.....	....	.....	27	.....	.....	42.2	.....	C. J.	
171	.....	0	100	.....	.....	.....	.....	.....	.....	....	.....	.....	.....	.....	15.2	17.0	We.	

In the above table the figures of order of ductility, malleability, hardness, and fusibility (see also Plate XV) are taken from Mallet's experiments on a series of 16 alloys,* the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals represented by Mallet as 0.

The relative ductility given in the table, of the alloys experimented on the board, is the proportionate extension of the exterior fibers of the pieces tested by torsion as determined by the autographic strain-diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson (Plate XV), are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1,000. The word "broke" in this column indicates the fact that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron.

The figures of specific gravity show a fair agreement among the several authorities in the alloys containing more than 35 per cent. of tin, except those given by Mallet, which are in general very much lower than those of all the other authorities. In the alloys containing less than 35 per cent. of tin there is a wide variation among all the different authorities, Mallet's figures, however, being generally lower than the others. Several of the figures of specific gravity have been selected from Riche's results of experiments on the effects of annealing, tempering, and compression, which show that the latter especially tends to increase the specific gravity of all the alloys containing less than 20 per cent. tin to about 8.95. This result, as stated in the discussion on specific gravity (page 377), is due largely to the closing up of the blowholes, and thus diminishing the porosity. The specific gravity of 8.953 was obtained by Major Wade by casting a small bar in a cold iron mold from the same metal which gave a specific gravity of only 8.313 when cast in the form of a small bar in clay mold. The former result is exceptionally high, and indicates, the probability that every circumstance of the melting, pouring, casting, and cooling was favorable to the exclusion of the gas which forms blowholes, and to the formation of a perfectly compact metal.

Plate XII gives a comparison of the figures of specific gravity obtained by different experimenters.

The figures of tenacity given by Mallet, Muschenbroek, and Wade agree with those found in the experiments described in this report as closely as could be expected from the very variable strengths of alloys of the same composition which have been found by all experimenters.

Mallet's figure for copper, 24.6 tons or 55,104 pounds, is certainly much too high for cast copper; the piece which he tested was probably rolled or perhaps drawn into wire. Haswell's Pocket Book gives the following for the tensile strength of copper; the names of the authorities are not given:

	Pounds per square inch.
Copper, wrought	34,000
Copper, rolled	36,000
Copper, cast (American)	24,250
Copper, wire	61,200
Copper, bolt	36,800

*See appendix.

The figure for cast American copper is evidently taken from the experiments of Major Wade.

The figures obtained by the writer for alloys of 7.5, 10, and 12.5 per cent. tin, viz, 27,900, 26,860, and 31,100 pounds, are much less than is usually given as the strength of gun-metal. It must be remembered, however, that bronze guns are usually cast under the pressure of a head of metal which tends to increase the strength and density. The strength of the upper part of a gun-casting, or sinking head, is not greater than those of the small bars which have been tested in these experiments. The table shows the figures of Major Wade for the mean density and tenacity of a lot of 83 gun-heads of one composition, and of 12 of another composition, the figures for tenacity being respectively 26,655 and 26,011 pounds per square inch.

The strength of gun-bronze, as found in the guns, is not given in the table, which is designed to compare only the various authorities on the tenacities of the alloys only, as cast under ordinary conditions, and not when compressed, rolled, or cast under pressure.

The following are a few extracts which have been made from the report of Major Wade concerning the strength and density of gun-bronze:

Bronze guns made at Chicopee, Mass., 1850.

	Specific gravity.	Tenacity.
Tin, 1 part	7.297	2,122
Copper, 8 parts (mean of 9 samples)	8.672	24,252
Mean of 83 guns	8.751	.....
Mean of 83 gun-heads	8.523	29,655

Extreme variation of six samples from different parts of the same gun (a 32-pounder howitzer): Specific gravity, 8.487 to 8.835; tenacity, 26,428 to 52,192. Extreme variation of all the samples tested: Specific gravity, 8.308 to 8.850; tenacity, 23,108 to 54,531. Extreme variation of all the samples from the gun-heads: Specific gravity, 8.308 to 8.756; tenacity, 23,529 to 35,484.

The materials used in all these castings were of the same quality; they were melted, cast, and cooled in the same manner, and were designed to be similarly treated in all respects.

Bronze guns made at South Boston, Mass., 1850—*12-pounder howitzers. Composition*, 10.71 *parts tin in* 100.

	Specific gravity.	Tenacity.
Mean of 12 gun-heads	8.353	26,011
Mean of 12 small bars cast with gun	8.800	52,253

The small bars were cast in the same mold as the gun and were subjected to the pressure of the sinking head. Major Wade remarks that the great superiority of the small bars over the gun-heads may be attributed to their cooling rapidly at first, and until they become solid, and to their subsequent cooling being retarded by the adjacent liquid mass of metal in the gun-head. The bar is in contact at one end with the gun-head, and any contraction which may occur in it after its solidification is supplied by the liquid metal in the head, with a force due to its column of pressure. This fills all cavities and gives compactness to the bar. The heat in the massive head which joins the bar controls and prolongs its cooling. Small bars, cast in separate molds, are cooled

pidly from first to last, and the cavities formed during their contraction e not supplied from any separate source. To these circumstances we ust attribute their inferiority to the bars cast in the gun-molds.

Three howitzers, Nos. 27, 28, and 29, were cast from the same liquid etal contained in a crane-ladle. No. 27 was cast when the metal was the highest temperature; No. 28 was cast fifteen minutes later; and o. 29 fourteen minutes after No. 28. The following results were ob-ined:

Time of metal in ladle, minutes.	Temperature of metal at casting.	Specific gravity—				Tenacity—		
		Of gun-heads	Of entire gun.	Of small bars cast in—		Of gun-heads.	Of small bars cast in—	
				Gun-mold.	Separate mold.		Gun-mold.	Separate mold.
0	Highest.....	7.986	8.195	8.686	8.554	17,761	50,974	31,132
15	Mean	8.351	8.551	8.823	8.447	28,995	52,330	28,153
29	Lowest.....	8.538	8.752	8.846	8.376	23,722	56,760	28,082

In casting another howitzer, No. 30, small test-bars were cast in sep-rate molds, one of which was of cast iron, to ascertain the effect of idden cooling, and the others were of clay, similar to the gun-mold. he tests of all the samples from this casting were as follows:

	Specific gravity.	Tenacity.
mall bars cast separately in iron mold.....	8.953	37,688
mall bars cast separately in clay mold	8.313	25,783
mall bar cast in gun-mold	8.895	53,798
un-head samples.....	8.490	35,578
inished howitzer.....	8.733	

In the conclusion to his report on gun-bronze Major Wade says: The general results which are exhibited in this report, on the qualities f bronze as they are found in guns, are mostly of a negative character. hey expose defects in density and strength, develop the heterogeneous exture of the metal in different parts of the same gun, and show the regularity and uncertainty of quality which attend the casting of all uns, although made from similar materials, treated in like manner. The scertained facts which this report exhibits, although they relate chiefly o existing imperfections in the art of manufacturing bronze, will, it is elieved, be found useful. They may serve to awaken the attention of hose who may henceforth be concerned in conducting this branch of ervice, and to suggest such improved methods of treating the materi-ls as will ultimately raise our knowledge of the art to an equality with at which has been attained in the manufacture of iron cannon."

That the strength of ordinary ordnance-bronze is still variable, twenty ears after Major Wade's report was written, is shown by the following cords of twelve tests made by the Ordnance Department, United States avy, and furnished to the writer by Capt. William N. Jeffers, United ates Navy, Chief of the Bureau of Ordnance.

Navy ordnance-bronze tested in 1875 *and* 1876 *at Washington, D. C.*

Mark.	Tensile strength per square inch of—		Permanent elongation in parts of original length.	Permanent reduction of area in parts of original.	Specific gravity.	
	Original section.	Fractured section.				
M 1, 3-4-75	42,037	70,000	.4795	.40		
M 2, 3-4-75	41,768	71,600	.478	.417		
BB, IX	22,385		.100			Full of large tin spots.
M 2, 5-6-75	45,737		.522	.470		
No. 3, 8-21-75	49,772	65,600	.2603	.240	8.878	Cast in chill mold.
No. 2, 8-21-75	48,000	60,000	.211	.20		Cast in chill mold.
GB 2, 5-6-75	35,820		.4975	.50		
GB 3, 5-6-75	20,818		.0291		8.392	Flaw in the breaking portion.
B 3 L, 12-70-75	33,630	39,000	.135	.134		Cast in chill mold.
M 1 C, 3-11-76	51,459	91,600	.580	.438		
B 2 C, 3-11-76	45,837	73,450	.396	.376		Cast in chill mold.
B 3 C, 3-11-76	44,869	71,600	.415	.373	8,853	Cast in chill mold.

The guns cast in chill molds were composed of 10 parts of copper to 1 part of tin; the others were of 9 parts of copper to 1 part of tin.

That a great improvement may be made in the density and tenacity of gun-bronze by compression has been shown by the experiments of Mr. S. B. Dean, in Boston, Mass., in 1869, and by those of General Uchatius, in Austria,* in 1873. The former increased the density of the metal next the bore of the gun from 8.321 to 8.875, and the tenacity from 27,238 to 41,471 pounds per square inch. The latter by a similar process obtained the following figures for tenacity:

	Pounds per square inch.
Bronze with 10 per cent. tin	72,053
Bronze with 8 per cent. tin	73,958
Bronze with 6 per cent. tin	77,656

The density of these specimens is not given, but it probably approaches very closely to 8.95. It is believed that the experiments of General Uchatius are still in progress.

The experiments of Riche have also shown the increase of density by compression and tempering. A translation of his paper on this subject is given in the appendix.

The table of comparison of authorities is by no means complete. No account is taken of a vast number of ancient bronzes, weapons, medals, coins, and sonorous instruments, which have been described by various writers. These, however, differ but little in composition and properties from the ordnance and bell metal given in the tables.

It will be observed that while there is considerable irregularity in the tenacity of the alloys containing more than 27.5 per cent. of tin, they are all extremely weak, the highest strength found by any experimenter being only 8,736 pounds, and valueless for all purposes in which strength is required.

It has been shown that the useful alloys, those which contain less than 27.5 per cent. of tin, have strengths which are nearly proportional to their densities. A systematic investigation remains yet to be made to ascertain the various causes which operate to produce the blow-holes which are the principal cause of the lack of density, and the means which may be taken to prevent the operation of these causes.

* Ordnance Notes No. XL, Washington, D. C., 1876.

As before stated, compression of the metal, either in the fluid state or
er it has solidified, increases the density and consequently the strength,
closing the blow-holes and compressing the gas which the blow-holes
ntain.

If the formation of the gas which causes these blow-holes can be pre-
nted, or if it can be removed from the metal while the latter is still in
luid state, it is evident that the cast metal will be entirely free from
em, and a metal of greater density and strength will be obtained
ich may not need further compression.

No means has yet been discovered by which this desirable result may
accomplished, but it is not improbable that it may be done by a
per system of treatment of the fluid metal, or by the use of fluxes
ich shall chemically unite with the gas of the blow-holes and prevent
existence in the gaseous state. The subject offers a fruitful field for
periment, one which it is proposed to explore after concluding the
searches in progress on castings of copper-tin, copper-zinc, and triple
oys.

[*First Series.*]

RECORD OF TESTS BY TRANSVERSE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXI.—CAST COPPER.

Original mark: No. 1.—Material: Copper, cast in hot iron mold.—Dimensions: Length between supports, $l = 22''$. Breadth, $b = 0.994''$. Depth, $d = 1.010''$.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$
Pounds.	*Inches.*	*Inches.*		*Pounds*	*Inches.*	*Inches.*	
7	0.004	.....	.....	350	0.123	.....	7,481,071
12	0.006	.....	.....	0	.....	0.032	.....
20	0.006	.....	.....	400	0.154	.....	6,819,089
30	0.008	.....	.....	0	.....	0.054	.....
0	.....	0.0024	.....	450	0.203	.....	5,813,338
40	0.010	.....	.....	0	.....	0.091	.....
50	0.009	.....	.....	500	0.265	.....	4,943,681
60	0.009	.....	.....	0	.....	0.147	.....
70	0.016	.....	.....	550	0.348	.....	4,135,055
80	0.018	.....	.....	0	.....	0.223	.....
90	0.022	.....	.....	550	0.384	.....	.....
100	0.026	.....	.....	600	0.442	.....	2,940,095
0	.....	0.007	.....	0	.....	0.295	.....
125	0.022	.....	15,241,676	600	0.534	.....	.....
150	0.027	.....	14,625,955	In 5 m.	0.543	.....	.....
0	.....	0.005	.....	625	0.637	.....	.....
200	0.038	.....	11,906,605	650	0.707	.....	2,404,496
225	0.052	.....	.....	0	.....	0.578	.....
250	0.073	.....	9,044,333	549	2.306	.....	Broke.
0	.....	0.010	.....				
275	0.085	.....	.....				
0	.....	0.014	.....				
300	0.098	.....	8,063,308				
0	.....	0.018	.....				
325	0.109	.....	.....				
0	.....	0.025	.....				

At 650 pounds a crack appeared on the under side of the bar. After reading the set, the bar sank rapidly under 549 pounds, and broke.

Breaking load 650 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=21,251.$

TABLE XXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 2.—Material: Alloy.—Original mixture: 98.1 Cu 1.9 Sn.—Analysis: 97.89 Cu, 1.90 Sn. Cast in dry sand.—Dimensions: Length between supports, 22". Breadth, 1.011". Depth, 1.005".

5	0.008	.....	.....	325	0.297	.....	.....
10	0.0024	.....	.....	350	0.368	.....	2,495,107
15	0.0039	.....	.....	375	0.577	.....	.....
20	0.0055	.....	.....	The deflection increased rapidly with time.			
30	0.0080	.....	.....				
40	0.0095	.....	.....	0	.....	0.537	.....
50	0.012	.....	.....	400	0.836	.....	1,253,455
60	0.013	.....	.....	425	1.120	.....	.....
70	0.014	.....	.....	0	.....	1.017	.....
80	0.016	.....	.....	450	1.454	.....	809,888
90	0.017	.....	.....	475	1.762	.....	.....
100	0.020	.....	13,487,674	In 3 m.	2.053	.....	.....
0	.....	0.000	.....	0	.....	1.931	.....
125	0.030	.....	11,153,271	500	2.108	.....	.....
175	0.041	.....	11,324,079	In 10 m.	2.596	.....	.....
200	0.054	.....	9,798,737	525	2.738	.....	.....
0	.....	0.0095	.....	550	3.147	.....	456,618
225	0.069	.....	8,608,354	In 3 m.	4.305	.....	.....
250	0.092	.....	7,161,098	575	4.561	.....	.....
0	.....	0.045	.....				
275	0.124	.....	.....				

The deflection increased with time, but the test was continued without stopping.

300	0.202	.....	3,900,516
0	.....	0.136	.....

Bar bent rapidly, and slipped through between supports.

Breaking load (considered to be that which causes a deflection of $3\frac{1}{8}''$), 550 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=17,872.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXIII.—ALLOY OF COPPER AND TIN.

l mark: No. 3.—Material: Alloy.—Original mixture: 96.27 Cu, 3.73 Sn.—Analysis: 96.06 Cu, 3.76 Sn.—Dimensions: Length between supports, 22″. Breadth, 1″. Depth, 0.995″.

Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\triangle bd^3}(P+4)$	Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\triangle bd^3}(P+4)$
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0008			In 20 m.	0.601		
0.0016			In 30 m.	0.618		
0.0032			In 40 m.	0.630		
0.0047			In 50 m.	0.642		
0.007			1 hour	0.650		
0.010			0		0.524	
	0.0016		700	0.658		
0.017			725	0.669		
0.021		13,262,817	750	0.701		
0.023			In 5 m.	0.846		
0.026		15,862,408	In 10 m.	0.890		
	0.0624		In 20 m.	0.913		
0.032		14,980,447	In 25 m.	0.925		
0.041		13,325,025	0		0.780	
0.045			775	0.946		
0.051		13,337,830	800	0.972		1,698,081
	0.004		In 5 m.	1.217		
0.054			In 15 m.	1.264		
0.060		13,56[illegible],883	0		1.110	
0.069		13,739,654	825	1.280		
	0.066		850	1.323		
0.077			In 5 m.	1.583		
0.083		13,035,420	In 45 m.	1.732		
	0.010		15h 45m	1.882		
0.085			0		1.713	
0.095		12,798,349	875	1.892		
	0.014		900	1.929		1,255,041
0.102			In 5 m.	2.095		
0.122		11,063,497	In 15 m.	2.162		
	0.025		In 30 m.	2.256		
0.124			In 45 m.	2.319		
0.138		10,751,086	0		2.122	
	0.042		925	2.335		
0.158			950	2.402		
0.181		8,936,754	In 5 m.	2.586		
0.229			In 15 m.	2.662		
0.244			975	2.713		
0.252			In 5 m.	2.988		
	0.108		In 10 m.	3.091		
0.268			1,000	3.118		862,341
0.287			In 5 m.	3.540		
0.382			In 15 m.	3.660		
0.410			In 45 m.	4.102		
0.421			1h 15m	7.634	Tray reached bottom of supports.	
	0.302					
0.429			Breaking load, P=1,000 pounds.			
0.441		4,275,193				
0.559			Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=33,232$.			
0.583						

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOL

TABLE XXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 4.—Material: Alloy.—Original mixture: 92.8 Cu, 7.2 Sn.—Dimensions: between supports, 22″. Breadth, 0.997″. Depth, 1.012″.

Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\triangle bd^3}(P+4)$	Load.	Deflection △	Set.	Modul elasti $E=\frac{l^3}{4\triangle bd}$
Pounds	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
6	0 0008	.....	.....	0	.....	0. 020	.....
10	0. 0016	.....	.....	750	0. 173	.....	.....
20	0. 0039	.....	.....	800	0. 199	.....	10, 4(
30	0. 007	.....	.....	0	.....	0. 049	.....
40	0. 010	.....	.....	850	0. 232	.....	.....
60	0. 013	.....	.....	900	0. 287	.....	8, 1
80	0. 017	.....	.....	0	.....	0. 116	.....
100	0. 020	.....	13, 396, 305	950	0. 348	.....	.....
0	.....	0. 000	.....	In 5 m.	0. 429	.....	.....
125	0. 024	.....	.....	1, 000	0. 491	.....	5, 2
150	0. 029	.....	13, 680, 575	In 5 m.	0. 584	.....	.....
175	0. 034	.....	.....	0	.....	0. 379	.....
200	0. 041	.....	12, 818, 227	1, 050	0. 620	.....	.....
0	.....	0. 000	.....	In 10 m.	0. 781	.....	.....
225	0. 045	.....	.....	1, 100	0. 858	.....	3, 3
250	0. 052	.....	12, 583, 801	In 10 m.	1. 031	.....	.....
0	.....	0. 0008	.....	0	.....	0. 807	.....
275	0. 057	.....	.....	1, 100	1. 053	.....	.....
300	0. 059	.....	13, 274, 439	1, 150	1. 155	.....	.....
0	.....	0. 000	.....	In 3 m.	1. 289	.....	.....
325	0. 063	.....	.....	1, 200	1. 384	.....	2, 2
350	0. 066	.....	13, 817, 863	In 10 m.	1. 824	.....	.....
375	0. 072	.....	.....	0	.....	1. 549	.....
400	0. 075	.....	13, 877, 197	1, 200	1. 824	.....	.....
0	.....	0. 000	.....	1, 250	1. 935	.....	.....
425	0. 079	.....	.....	In 10 m.	2. 178	.....	.....
450	0. 082	.....	14, 263, 420	In 30 m.	2. 281	.....	.....
475	0. 087	.....	.....	15h 30m	2. 638	.....	.....
0	.....	0. 0016	.....	0	.....	2. 343	.....
500	0. 095	.....	13, 677, 484	1, 250	2. 639	.....	.....
0	.....	0. 0024	.....	1, 300	2. 746	.....	1, 2
525	0. 102	.....	.....	In 10 m.	2. 911	.....	.....
550	0. 106	.....	13, 464, 355	In 30 m.	2. 966	.....	.....
0	.....	0. 0032	.....	1, 350	3. 226	.....	.....
575	0. 112	.....	.....	In 30 m.	6. 706	Tray reached bottor ports.	
0	.....	0. 0055	.....				
600	0. 124	.....	12, 548, 648	Breaking load, P=1,350 pounds.			
0	.....	0. 0095	.....				
650	0. 137	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=$			
0	.....	0. 013	.....				
700	0. 153	.....	11, 853, 945				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXV.—ALLOY OF COPPER AND TIN.

iginal mark: No. 5.—**Material**: Bronze.—Original mixture: 90 Cu, 10 Sn.—Analysis: 90.27 Cu, 9.58 Sn.—Dimensions: Length between supports, 22″. Breadth 1.008″. Depth, 0.993″.

oad.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
unds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
25	0.0068			0		0.202	
30	0.0063			950	0.424		
40	0.017			1,000	0.467		5,798,983
60	0.020			In 15 m.	0.550		
80	0.026			0		0.321	
00	0.030		9,350,764	1,050	0.595		
25	0.032			In 10 m.	0.693		
0		0.0024		0		0.445	
50	0.034		12,217,342	1,050	0.723		
00	0.043		12,796,662	1,100	0.849		3,507,489
50	0.053		12,926,853	In 10 m.	0.951		
00	0.063		13,015,713	0		0.672	
0		0.0024		1,100	0.971		
50	0.079		12,086,794	1,150	1.050		
0		0.047		In 5 m.	1.085		
00	0.093		11,717,459	0		0.817	
0		0.0024		1,150	1.109		
50	0.100		12,245,903	1,200	1.132		2,868,897
00	0.107		12,705,206	In 15 m.	1.609		
0		0.0047		1,250	1.757		
50	0.122		12,248,556	In 3 m.	1.997		
00	0.139		11,720,796	1,300	2.239		1,570,936
0		0.010		In 3 m.	2.656		
50	0.152			0		2.318	
0		0.010		1,350	2.683		
00	0.171		11,104,794	1,425	2.979		1,293,888
0		0.023		In 3 m.	3.129		
50	0.192			1,435	3.331		
0		0.036		1,485	3.447		
00	0.221		9,812,931	In 3 m.	4.589		
0		0.054		0		4.198	
50	0.256			1,485 in	7.534	Bar bent rapidly till tray	
0		0.081		10 m.		reached bottom of supports.	
00	0.306		7,968,600	Breaking load, 1,485 pounds.			
0		0.115		Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=49,400.$			
50	0.395						
5 m.	0.416						

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 6.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis: 87.25 Cu, 12.75 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.996″. Depth, 1.007″.

Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection. △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0024			650	0.269		
20	0.0055			700	0.328		5,651,
30	0.0079			In 10 m.	0.388		
40	0.0079			0		0.177	
60	0.011			750	0.421		
80	0.018			In 10 m.	0.496		
100	0.028		9,775,850	800	0.532		3,979
0		0.0016		In 15 m.	0.717		
125	0.032		10,614,421	0		0.453	
150	0.039		10,397,121	850	0.770		
0		0.0032		In 30 m.	0.972		
175	0.045		10,473,635	0		0.650	
200	0.051		10,532,146	900	1.024		2,324
0		0.0032		In 45 m.	1.205		
250	0.069		9,692,628	0		0.913	
300	0.085		9,416,976	950	1.285		
0		0.0047		In 15 m.	1.624		
350	0.114		8,176,271	1,000	1.685		1,568
400	0.139		7,654,855	In 15 m.	2.114		
0		0.008		0		1.717	
450	0.156		7,662,812	1,050	2.291	Broke about 10 seconds after placing the weight on the bar.	
500	0.176		7,540,061				
0		0.027		Breaking load, 1,050 pounds.			
550	0.201		7,257,225				
600	0.236		6,738,789	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=$			
0		0.058					

TABLE XXVII.—ALLOY OF COPPER AND TIN

Original mark: No. 7.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.95 Cu, 19.05 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 1.011″.

5	0.0008			850	0.172		
10	0.0016			875	0.177		
20	0.0055			900	0.184		12,681
50	0.0095			0		0.0103	
75	0.021			925	0.188		
100	0.025		10,737,827	950	0.192		
125	0.028		11,891,996	975	0.197		
150	0.033		12,045,639	1,000	0.201		12,893
175	0.037		12,487,468	0		0.012	
200	0.043		12,245,726	1,050	0.209		
0		0.0024		0		0.013	
225	0.045			1,075	0.213		
250	0.051		12,855,428	1,100	0.219		13,042
275	0.057			1,150	0.231		
300	0.063		12,455,356	1,200	0.256		12,129
0		0.0039		0		0.026	
325	0.069			1,250	0.269		
350	0.073		12,517,091	1,300	0.285		11,810
375	0.077			0		0.039	
400	0.081		12,874,176	1,350	0.305		
0		0.0047		1,400	0.320		11,322
425	0.083			0		0.055	
450	0.087			1,450	0.339		
475	0.094			1,500	0.360		10,785
500	0.098		13,274,787	0		0.075	
0		0.0063		1,550	0.386		
525	0.103			1,600	0.415		9,970
550	0.105			0		0.099	
575	0.114			1,650	0.441		
600	0.122		12,779,097	1,700	0.470		9,353
0		0.0063		0		0.126	
625	0.128			1,750	0.510		9,209
650	0.132			In 15 h	0.537		
675	0.134			0		0.169	
700	0.140		12,979,791	1,520	0.469		
0		0.0039		1,620	0.492		
725	0.152			1,750	Broke 10 seconds after putting on pound of the weight.		
750	0.155						
785	0.163			Breaking load, 1,750 pounds.			
800	0.167		12,426,896				
0		0.0063		Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=$			
825	0.170						

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

IANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXVIII.—ALLOY OF COPPER AND TIN.

mark No. 8.—Material: Alloy.—Original mixture: 76.32 Cu, 23.68 Sn.—Analysis: 76.63 Cu, 3.24 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 1.002″.

Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$
Inches.	*Inches.*		*Pounds*	*Inches*	*Inches.*	
0.0008	.....	.....	550	0.110	.....	.....
0.0016	.....	.....	575	0.116	.....	.....
0.0039	.....	.....	600	0.120	.....	13,345,659
0.0095	.....	.....	0	.....	0.0055	.....
0.014	.....	.....	625	0.124	.....	.....
0.020	.....	.....	675	0.133	.....	.....
0.024	.....	11,489,377	700	0.143	.....	13,053,021
0.028	.....	.....	725	0.147	.....	.....
0.035	.....	11,666,136	750	0.151	.....	.....
0.045	.....	12,019,656	775	0.156	.....	.....
.....	0.0039	.....	800	0.161	.....	13,240,505
0.047	.....	.....	825	0.165	.....	.....
0.054	.....	12,471,374	850	0.173	.....	.....
0.059	.....	.....	875	0.175	.....	.....
0.062	.....	13,000,384	900	0.179	.....	13,394,284
0.069	.....	.....	0	.....	0.0055	.....
0.073	.....	.....	925	0.184	.....	.....
0.081	.....	13,224,211	950	0.191	.....	13,243,091
0.085	.....	.....	0	.....	0.0055	.....
0.092	.....	.....	975	Broke just as the weight was applied.		
0.098	.....	.....	Breaking weight, 975 pounds.			
0.101	.....	13,230,722	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=32,210.$			
0.106	.....	.....				

TABLE XXIX.—ALLOY OF COPPER AND TIN.

mark: No. 9.—Material: Alloy.—Original mixture: 70 Cu, 30 Sn.—Analysis: 69.84 Cu, 29.88 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.992″. Depth, 1′.

0.0008	.....	.....	240	0.039	.....	.....
0.0039	.....	.....	250	0.041	.....	16,624,412
0.0071	.....	.....	260	0.044	.....	.....
0.0087	.....	16,656,009	280	0.051	.....	.....
0.0111	.....	.....	300	0.054	.....	15,106,912
0.017	.....	.....	0	.....	0.0008	.....
0.020	.....	13,954,034	320	0.056	.....	.....
0.022	.....	.....	340	0.060	.....	.....
0.025	.....	.....	350	0.062	.....	15,321,736
0.026	.....	15,894,387	0	.....	0.0039	.....
0.027	.....	.....	360	Broke just as load was applied.		
0.030	.....	.....	Breaking load, 360 pounds.			
0.034	.....	16,104,514	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=12,076.$			
.....	0.000	.....				
0.036	.....	.....				

TABLE XXX.—ALLOY OF COPPER AND TIN.

l mark: No. 10.—Material: Alloy.—Original mixture: 68.25 Cu, 31.75 Sn.—Analysis: 68.58 Cu, 31.26 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.990″. Depth, 1.004″.

0.0008	.....	.....	175	0.031	.....	.....
0.0039	.....	.....	200	0.035	.....	15,486,233
0.0087	.....	.....	0	.....	0.0016	.....
0.0103	.....	13,929,650	225	0.039	.....	.....
0.012	.....	.....	250	0.043	.....	15,694,556
0.016	.....	.....	275	Broke about 4 seconds after putting on weight.		
0.019	.....	14,543,316	Breaking load, 275 pounds.			
.....	0.000	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=9192.$			
0.022	.....	.....				
0.026	.....	15,737,332				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY

TABLE XXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 11.—Material: Alloy.—Original mixture: 65 Cu, 35 Sn.—Analysis: 65.33 Cu, 34.67 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.982″. Depth, 1.003″.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E\frac{l^3}{4\Delta bd^3}(P+4)$
Pounds	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
6	0.0008			110	0.017		
90	0.0039			120	0.018		18,508,501
30	0.0047			130	0.019		
40	0.0071			140	0.020		19,344,308
50	0.0095		15,521,868				
60	0.011			Broke about 5 seconds after putting on weight.			
80	0.013			Breaking load, 140 pounds.			
100	0.016		17,463,665				
0		0.000		Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=4,775.$			

TABLE XXXII.—ALLOY OF COPPER AND TIN.

Original mark: No 12.—Material: Alloy.—Original mixture: 61.71 Cu, 38.29 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.992″. Depth, 1.000″.

6	0.0008			0		0.0071	
20	0.0079			70	0.032		6,205,519
25	0.0087		8,944,893	0		0.0103	
30	0.0095		9,603,989	80	Broke just as weight was applied.		
40	0.018		6,559,587	Breaking load, 80 pounds.			
50	0.021		6,900,346				
60	0.028		6,133,626	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=2,761.$			

TABLE XXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 13.—Material: Alloy.—Original mixture: 56.32 Cu, 43.68 Sn.—Analysis: 56.70 Cu, 43.17 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 0.990″.

7	0.0008			40	0.0087		13,902,301
10	0.0016			50	0.0103		14,693,513
20	0.0039		16,916,087	0		0.000	
25	0.0055			60	Broke just as weight was applied.		
30	0.0063		14,835,139	Breaking load, 60 pounds.			
0		0.000					
35	0.0079			Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=2,126.$			

TABLE XXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 14.—Material: Alloy.—Original mixture: 51.80 Cu, 48.20 Sn.—Analysis: Top, 62.27 Cu, 37.58 Sn. Middle, 51.62 Cu, 48.09 Sn. Bottom, 38.41 Cu, 61.04 Sn.—Dimensions: Length between supports, 17⅞″. Breadth, 1.005″. Depth, 0.0992″.

12	0.0024			80	0.028		4,366,023
20	0.0055			0		0.013	
25	0.0087		4,851,137	90	0.032		
30	0.0095			100	0.035		4,324,442
40	0.012		4,925,769	0		0.015	
0		0.0071		110	0.037		
50	0.013			120	0.040		4,511,661
60	0.018		5,174,546	0		0.017	
0		0.0087		130	0.040		
65	0.021			140	Broke in placing weight on bar.		
0		0.010		Breaking load, 140 pounds.			
70	0.022						
0		0.011		Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=3,877.$			

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XXXV.—ALLOY OF COPPER AND TIN.

ginal mark: No. 15.—Material: Alloy.—Original mixture: 47.95 Cu, 52.05 Sn.—Analysis: 47.61 Cu, 52.14 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.990″. Depth, 1″.

ad.	Deflection $\triangle$	Set.	Modulus of elasticity. $E\frac{l^3}{4\triangle bd^3}(P+4)$	Load	Deflection $\triangle$	Set.	Modulus of elasticity. $E\frac{l^3}{4\triangle bd^3}(P+4)$
nds	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
8	0. 0008	.....	.....	70	0. 0126	.....	.....
12	0. 0024	.....	.....	80	0. 0142	.....	15, 906, 105
20	0. 0047	.....	.....	0	.....	0. 000	.....
25	0. 0055	.....	14, 177, 779	90	0. 0166	.....	.....
30	0. 0071	.....	.....	100	0. 019	.....	14, 718, 131
0	.....	0. 000	.....	105	Broke about 5 seconds after putting on the weight.		
35	0. 0071	.....	.....	Breaking load, 105 pounds.			
40	0. 0079	.....	.....				
50	0. 0087	.....	17, 039, 130	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=3,600$.			
60	0. 0103	.....	.....				

TABLE XXXVI.—ALLOY OF COPPER AND TIN.

ginal mark': No. 16.—Material: Alloy.—Original mixture: 44.63 Cu, 55.37 Sn.—Analysis: 44.52 Cu, 55.28 Sn.—Dimensions: Length between supports, 22″. Breadth, 1″. Depth, 0.994″.

6	0. 0008	.....	.....	0	.....	0. 000	.....
10	0. 0016	.....	.....	110	0. 021	.....	.....
20	0. 0032	.....	.....	120	0. 025	.....	13, 444, 141
30	0. 0047	.....	19, 607, 962	0	.....	0. 0016	.....
40	0. 0063	.....	.....	130	0. 026	.....	.....
50	0. 0087	.....	16, 823, 869	140	Broke immediately after putting on weight.		
0	.....	0. 000	.....	Breaking load, 140 pounds.			
60	0. 012	.....	.....				
70	0. 015	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=4,776$.			
80	0. 017	.....	.....				
00	0. 018	.....	15, 660, 735				

TABLE XXXVII.—ALLOY OF COPPER AND TIN.

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ginal mark: No. 17.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: Top, 45.93 1, 53.80 Sn. Bottom, 38.83 Cu, 60.79 Sn. Mean, 42.38 Cu, 57.30 Sn.—Dimensions: Length between pports, 22″. Breadth, 1.002″. Depth, 0.990″.

12	0. 0008	.....	.....	150	0. 017	.....	.....
20	0. 0016	.....	.....	0	.....	0. 0016	.....
30	0. 0039	.....	.....	160	0. 022	.....	20, 451, 411
40	0. 0063	.....	.....	170	0. 024	.....	.....
50	0. 0079	.....	18, 752, 912	180	0. 026	.....	19, 415, 409
60	0. 0095	.....	.....	190	0. 028	.....	.....
70	0. 010	.....	.....	200	0. 030	.....	18, 289, 876
80	0. 012	.....	19, 294, 372	0	.....	0. 0024	.....
90	0. 013	.....	.....	210	0. 042	Broke about 20 seconds after applying weight.	
00	0. 014	.....	20, 380, 620	Breaking weight, 210 pounds.			
0	.....	0, 000	.....				
20	0. 016	.....	21, 261, 981	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=7,172$.			
40	0. 017	.....	23, 238, 907				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

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TABLE XXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 18.—Material: Alloy.—Original mixture: 39.20 Cu 60.80 Sn.—Analysis: 38.37 Cu 61.32 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.983″. Depth, 1.003″.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity. $E\frac{l^3}{4\Delta bd^3}(P-$
Pounds	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
4	0.0008	.....	.....	125	0.028	.....	12,302,33
20	0.0032	.....	.....	150	0.035	.....	11,749,22
25	0.0039	.....	19,855,913	175	0.042	.....	11,350,47
30	0.0047	.....	.....	200	0.047	.....	11,590,14
40	0.0087	.....	.....	0	.....	0.0016	.....
50	0.0103	.....	13,999,516	225	0.060	.....	10,191,56
60	0.013	.....	.....	0	.....	0.0039	.....
70	0.016	.....	.....	250	Broke just as weight was applied.		
80	0.019	.....	11,805,440	Breaking load, 250 pounds.			
90	0.021	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=54$			
100	0.023	.....	12,074,300				
0	.....	0.0008	.....				

TABLE XXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 19.—Material: Alloy.—Original mixture: 34.95 Cu, 65.05 Sn.—Analysis: 34.20 Cu 65.80 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.991″. Depth, 1.004″.

6	0.0008	.....	.....	100	0.025	.....	11,041,
10	0.0016	.....	.....	0	.....	0.0063	.....
20	0.0055	.....	.....	120	0.033	.....	9,652,
30	0.0071	.....	.....	130	0.036	.....	.....
0	.....	0.0008	.....	0	.....	0.118	.....
40	0.0103	.....	.....	140	0.039	.....	9,525,
50	0.0134	.....	10,696,444	150	0.043	.....	9,506,
0	.....	0.0016	.....	160	Broke in putting on weight.		
60	0.017	.....	.....	Breaking load, 160 pounds.			
70	0.018	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=5$			
80	0.021	.....	10,617,212				
0	.....	0.0032	.....				

TABLE XL.—ALLOY OF COPPER AND TIN.

Original mark: No. 20.—Material: Alloy.—Original mixture: 28.72 Cu, 71.28 Sn.—Analysis: 25.20 Cu 73.80 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.990″. Depth, 1.002″.

4	0.0008	.....	.....	130	0.047	.....	.....
12	0.0024	.....	.....	140	0.051	.....	.....
20	0.0039	.....	.....	0	.....	0.014	.....
30	0.0035	.....	.....	150	0.056	.....	7,350
40	0.012	.....	9,982,832	160	0.061	.....	.....
50	0.015	.....	9,622,432	0	.....	0.017	.....
60	0.018	.....	.....	180	0.075	.....	.....
0	.....	0.0016	.....	200	0.091	.....	5,991,
70	0.023	.....	.....	0	.....	0.029	.....
80	0.028	.....	0.018,694	220	0.109	.....	.....
90	0.029	.....	.....	240	0.121	.....	5,389,
100	0.035	.....	7,942,325	Broke 30 seconds after applying weight.			
0	.....	0.0039	.....	Breaking load, 240 pounds.			
120	0.044	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=$			
0	.....	0.010	.....				

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TABLE XLI.—ALLOY OF COPPER AND TIN.

Mark: No. 21.—Material: Alloy.—Original mixture: 24.38 Cu, 75.62 Sn.—Analysis: 24.35 Cu, 75.29 Sn.—Dimensions: Length between supports, 22″. Breadth, 1.002″. Depth, 0.995″.

Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection. △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(+P4)$.
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0008	.....	.....	200	0.086	.....	6,397,033
0.0032	.....	.....	0	.....	0.028	.....
0.0071	.....	12,914,205	260	0.142	.....	5,013.747
0.0103	.....	11,520,262	0	.....	0.056	.....
0.0142	.....	10,255,393	300	0.178	.....	4,605,751
0.0158	.....	.....	350	0.230	.....	4,150,805
0.023	.....	9,849,141	0	.....	0.095	.....
0.029	.....	9,671,241	360	0.245	.....	.....
0.035	.....	.....	370	0.269	.....	3,749,438
0.041	.....	.....	Broke 10 seconds after putting on weight.			
.....	0.0047	.....	Breaking load, 370 pounds.			
0.054	.....	7,690,841				
.....	0.0095	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=12,408$.			
0.066	.....	.....				
.....	0.0166	.....				

TABLE XLII.—ALLOY OF COPPER AND TIN.

Mark: No. 22.—Material: Alloy.—Original mixture: 21.18 Cu, 78.82 Sn.—Analysis: 20.25 Cu 63 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 1.005″.

0.0008	.....	.....	180	0.134	.....	3,545,673
0.0047	.....	.....	In 5 m.	0.144	.....	.....
0.0079	.....	.....	0	.....	0.076	.....
0.0095	.....	9,743,644	200	0.164	.....	3,301,693
0.015	.....	.....	In 10 m.	0.189	.....	.....
0.018	.....	7,962,908	0	.....	0.110	.....
0.032	.....	6,967,544	225	0.203	.....	.....
.....	0.0047	.....	In 15 m	0.243	.....	.....
0.039	.....	.....	250	0.253	.....	2,664,794
.....	0.0087	.....	In 15 m.	0.302	.....	.....
0.043	.....	6,419,710	0	.....	0.189	.....
.....	0.0118	.....	300	0.345	.....	2,338,863
0.066	.....	.....	Broke 20 seconds after putting on weight.			
.....	0.026	.....	Breaking load, 300 pounds.			
0.089	.....	4,592,838				
0.097	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=10,019$.			
0.124	.....	.....				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

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TABLE XLIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 23.—Material: Alloy.—Original mixture: 15.19 Cu, 84.81 Sn.—Anylysis: 15.08 Cu, 84.62 Sn.—Dimensions: Length between supports, 22″. Breadth, 1.004″. Depth, 0.995″.

Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\triangle bd^3}(P+4)$	Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\triangle bd^3}(P+4)$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
5	0.0008			In 1 m.	0.291		
10	0.0024			200	0.307		1,788,560
20	0.0079			In 1 m.	0.335		
25	0.0111		7,032,130	0		0.226	
40	0.021			210	0.347		
50	0.027		5,383,216	In 1 m.	0.366		
0		0.095		220	0.394		
60	0.032			230	0.425		
80	0.048			240	0.484		
0		0.020		250	0.535		1,277,885
100	0.071		3,942,637	0		0.394	
0		0.032		250	0.579		
120	0.101			In 1 m.	0.622		
140	0.133			0		0.500	
150	0.146		2,839,093	260	0.721		
160	0.185			270	0.858		859,553
170	0.206			Broke about 5 seconds after putting on weight.			
In 2 m.	0.221			Breaking load, 270 pounds.			
180	0.252			Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=9,063$.			
In 1 m.	0.255						
190	0.271						

TABLE XLIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 24.—Material: Alloy.—Original mixture: 11.84 Cu, 88.16 Sn.—Analysis: 11.49 Cu, 88.47 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.973″. Depth, 0.980″.

6	0.0008			In 1 m.	0.436		
20	0.0055			0		0.341	
25	0.0071		11,872,635	220	0.538		
30	0.0095		10,403,101	240	0.676		
40	0.013			250	0.778		948,990
50	0.017		9,233,203	260	0.884		
60	0.022			0		0.747	
75	0.030			270	0.975		
0		0.0063		In 2 m.	1.502		
100	0.054		5,598,312	280	1.597		
0		0.0205		In 2 m.	1.929		
125	0.089			290	2.128		
0		0.043		In 1 m.	2.562		
140	0.135			300	2.739		292,740
150	0.159		2,615,341	In 20 s.	5.849		
0		0.097		Bar bent rapidly after 300 pounds was placed on it, and broke in about 20 seconds. Reading of deflection just before breaking, 5.849 inches.			
160	0.191						
170	0.219			Breaking load, 300 pounds.			
180	0.247			Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=10,706$.			
0		0.176					
190	0.294						
200	0.341		1,738,934				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

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TABLE XLV.—ALLOY OF COPPER AND TIN.

ginal mark: No. 25.—Material: Alloy.—Original mixture: 9.7 Cu., 90.3 Sn.—Analysis: 8.57 Cu, 91.39 Sn.—Dimensions: Length between supports, 22″. Breadth, 1.002″. Depth, 1.006″.

oad.	Deflection. △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$	Load.	Deflection. △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\,\Delta\,bd^3}(P+4)$
unds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
4	0.0008			5h 10m	1.691		
10	0.0032			6h 40m	1.766		
20	0.0063			7h 40m	1.811		
25	0.0095		7,965,988	0		1.731	
30	0.012			160	1.815		
40	0.018			Left 15h	2.534		
50	0.026		5,419,830	0		2.455	
0		0.0042		160			
60	0.035			Left 1h 55m	2.697		
0		0.0118		3h 25m	2.782		
70	0.042			5h 10m	2.938		
0		0.016		7h 40m	3.136		
80	0.054		4,059,298	0		3.036	
0		0.024		160	3.798		
100	0.085		3,192,860	Left 15h			
0 m.	0.106			17h 45m	4.274		
0		0.067		18h 45m	4.349		
120	0.140		2,404,512	23h 40m	5.097		
0 m.	0.195			0		5.053	
140	0.221		1,700,339	160	5.207		
5 m.	0.319						
0		0.266					
n 10m	0.357						
10m	1.277						
0	1.205						
150	1.284						
160	1.294		330,731				
0 m.	1.319						
0m	1.463						
0m	1.530						

Left over night and found broken next morning. Total deflection before breaking nearly 8 inches. Time, 160 pounds remained on the bar *more* than 56 hours. Breaking load, 160 pounds.

Modulus of rupture $R=\frac{2}{3}\frac{l}{bd^2}(P+3)=5,305.$

TABLE XLVI.—ALLOY OF COPPER AND TIN.

ginal mark: No. 26.—Material: Alloy.—Original mixture: 4.29 Cu, 95.71 Sn,—Analysis: 3.72 Cu, 96.31 Sn.—Dimensions: Length between supports, 22″. Breadth, 1.005″. Depth, 1.005″

7	0.0008			170	0.706		
10	0.0016			0		0.639	
20	0.0055			180	0.883		543,726
25	0.0071		10,657,674	190	1.048		
30	0.0103		8,613,200	200	1.186		448,816
40	0.018			In 2m.	1.879		
50	0.025		6,636,071	In 3m.	2.127		
0		0.0063		0		2.064	
60	0.035			200	2.284		
0		0.0166		210	2.560		
70	0.051			In 2m.	3.658		
0		0.027		0		3.509	
80	0.077		2,846,501	210			
00	0.123		2,206,231				
0		0.091					
125	0.249		1,359,802				
0		0.209					
150	0.371		4,083,102				
160	0.540						

Bar bent rapidly till tray reached bottom of supports. Total deflection about 8 inches.

Breaking load (considered to be that load which produces a deflection of 3½ inches), 210 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=6,925.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

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TABLE XLVII.—ALLOY OF COPPER AND TIN.

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Original mark: No. 27.—Material: Alloy.—Original mixture: 1.11 Cu, 98.89 Sn.—Analysis: 0.7 99.02 Sn.—Dimensions: Length between supports, 22″. Breadth, 1″. Depth, 1.012″.

Load.	Deflection Δ	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection Δ	Set.	Modulus of elasticity $E=\frac{l^3}{4\Delta bd^3}(P$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
5	0.0008	.....	.....	100	0.417	.....	640,7
10	0.0024	.....	.....	In 5 m.	0.521	.....	.....
20	0.0087	.....	.....	0	.....	0.439	.....
0	.....	0.0024	.....	110	0.618	.....	.....
25	0.011	.....	6,771,517	In 5 m.	0.680	.....	.....
0	.....	0.0032	.....	0	.....	0.629	.....
30	0.014	.....	.....	120	0.736	.....	432,7
0	.....	0.0047	.....	In 15 m.	1.791	.....	.....
40	0.021	.....	.....	In 45 m.	2.539	.....	.....
0	.....	0.0071	.....	0	.....	2.459	.....
50	0.038	.....	3,649,983	120 in 45m	3.134	.....	.....
0	.....	0.020	.....	0	.....	3.078	.....
60	0.065	.....	.....	120	Left under strain overnight, and		
0	.....	0.044	.....	morning the tray was found to have reache			
70	0.106	.....	.....	bottom of the supports. Final deflection.			
80	0.180	.....	1,198,637	Breaking load, 120 pounds.			
0	.....	0.146	.....				
90	0.243	.....	.....	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)$			3.3
In 5 m.	0.306	.....	.....				
0	.....	0.269	.....				

TABLE XLVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 28.—Material: Alloy.—Original mixture: 0.557 Cu, 99.443 Sn.—Analysis: 0.3 99.46 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.989″. Depth, 1″.

3	0.0008	.....	.....	14h 5m.	1.945	.....	.....
10	0.0024	.....	.....	0	.....	1.896	.....
20	0.0055	.....	.....	110	1.965	.....	.....
25	0.0063	.....	12,389,141	In 20 m.	2.004	.....	.....
30	0.0079	.....	11,583,387	1h 50m.	2.138	.....	.....
40	0.0126	.....	9,395,659	In 3 h.	2.248	.....	.....
50	0.019	.....	7,649,833	4h 25m.	2.378	.....	.....
0	.....	0.0039	.....	7h 5m.	2.626	.....	.....
60	0.027	.....	.....	0	.....	2.579	.....
0	.....	0.0079	.....	110	2.634	.....	.....
70	0.037	.....	.....	120	2.650	.....	.....
0	.....	0.014	.....	In 5 m.	2.701	.....	.....
80	0.047	.....	4,810,533	1h 45m.	3.327	.....	.....
0	.....	0.021	.....	130	3.366	.....	.....
90	0.067	.....	.....	In 5 m.	3.437	.....	.....
0	.....	0.034	.....	In 35 m.	3.787	.....	.....
100	0.083	.....	3,372,617	130	Left under strain overnight, and		
In 5 m.	0.161	.....	.....	morning the tray was found to have reach			
In 10 m.	0.199	.....	.....	port. Total deflection, 8.114″.			
In 40 m.	0.295	.....	.....	Breaking load, 130 pounds.			
0	.....	0.200	.....				
100	0.311	.....	.....				
110	0.323	.....	924,227	Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)$			=4.
In 5 m.	0.406	.....	.....				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*First series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XLIX.—BAR OF CAST TIN.

nal mark: No. 29.—Material: Banca tin, cast in iron mold.—Dimensions: Length between supports, 22″. Breadth, 0.993″. Depth, 1.002″.

t. Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$	Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{l^3}{4\Delta bd^3}(P+4)$
ls. *Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0008			8.5 lb, in 5 m	0.282		
0.0032			0		0.265	
0.0055			85	0.340		
0.0095		6,734,838	In 10 m	0.840		
	0.0047		90	0.966		
0.012		6,218,983	90 lb. 10 m.	1.199		
0.015		6,039,908	0		1.155	
0.017			100	1.360		
	0.0055		In 5 m.	1.624		
0.021		5,582,107	In 20 m.	2.124		
	0.0095		0		2.065	
0.029			110	2.332		
	0.015		In 10 m.	8.395	Bar bent and tray reached bottom of supports.	
0.041		3,517,648				
	0.021					
0.062		2,750,622				
	0.043					
0.104						
	0.082					
0.218		1,026,751				

ck observed on under side of bar extending s half its breadth.

Breaking load, 110 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{l}{bd^2}(P+3)=3,740$.

TABLE L.—BAR OF CAS COPPER.

nal mark: No. 30.—Material: Lake Superior copper, cast in cold iron mold. Poured very hot.—Dimensions: Length between supports, 22″. Breadth, 0.99″. Depth, 0.98″.

Deflection △	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection △	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0033			640	1.37		
0.0060			680	1.63		
0.0116		9,851,369	720	1.93		1,065,786
0.0173		9,908,316	760	2.23		
0.0224		10,203,205	800	2.60		
0.0289		9,885,459	820	2.83		
	0.0029		840	3.09		
0.0355		9,657,120	860	3.49		720,375
0.0513		8,910,400	Supports slid out from under the bar. Placed on solid supports 20 inches apart, and applied 1,150 pounds, which gave a deflection of nearly 6 inches. Moved the supports to 10 inches apart and applied 3,000 pounds, when the bar broke after a deflection of 8 inches.			
0.0729		7,837,853				
	0.0260					
0.0964		7,112,607				
0.1280						
0.1705		5,361,919				
0.2253						
0.3079		3,711,460				
	0.2040					
0.4169						
0.5565						
0.7540		1,970,274				
0.9155						
1.1635		1,416,058				
	1.0085					
1.2105						

Breaking load, 860 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=29,848$.

NOTE.—The figures in the column headed "Load" are the applied weights plus one-half the weight of the bar between the supports. The scale-beam was balanced so as to read 3 pounds (or one-half the weight of bar between supports) when the bar was in position, before any pressure was applied to it.

RECORD OF TESTS BY TENSILE STRESS.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LI.—CAST COPPER.

Original mark: No. 1 A.—Material: Cast copper.—Dimensions: Length, 6″. Diameter, 0.795″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds	*Pounds.*	*Inches.*	
5,900	11,800	0.01	.0020
6,825	13,650	0.03	.0060
7,090	14,180	0.03	
Broke ¼ inch from end marked C.			

Diameter of fractured section, 0.790 inch.
Several blowholes in section; estimated area of blowholes, 0.053 square inch.
Tenacity per square inch original section, 14,180 pounds.
Tenacity per square inch, deducting blowholes, 15,865 pounds.
Tenacity per square inch in fractured section, 14,464 pounds.

TABLE LII.—CAST COPPER.

Original mark: No. 1 B.—Material: Cast copper.—Dimensions: Length, 6″. Diameter, 9.796″.

Load.	Load per square inch.	Elongation in 5.99 inches.	Elongation in parts of original length.
Pounds	*Pounds.*	*Inches.*	
4,550	9,100	0.01	.0017
5,670	11,340	0.02	.0033
Broke about 20 seconds after strain was applied ¼ inch from B end.			

Diameter of fractured section, 0.792 inch.
Estimated area of blowholes in section, 0.0573 square inch.
Tenacity per square inch in original section, 11,340 pounds.
Tenacity per square inch, deducting blowholes, 12,814 pounds.
Tenacity per square inch in fractured section, 11,509 pounds.

TABLE LII.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 A.—Material: Alloy.—Original mixture: 98.1 Cu, 1.9 Sn.—Analysis: 97.95 Cu, 1.88 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 4.98 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4,310	8,620	0.01	.0020
5,110	10,220	0.02	.0040
5,390	10,780	0.03	.0060
5,700	11,400	0.04	.0080
6,350	12,700	0.06	.0120
0		Set 0.05	
6,800	13,600	0.08	.0160
7,250	14,500	0.11	.0220
7,570	15,140	0.14	.0281
8,300	16,600	0.22	.0442
8,960	17,920	0.27	.0542
9,450	18,900	0.31	.0623
10,000	20,000	0.38	.0763
10,800	21,600	0.49	.0984
11,600	23,200	0.56	.1125
12,000	24,000	0.62	.1245
12,600	25,200	0.78	.1566

Broke at A end.
At 10,800 the elongation was observed to increase with time.
Diameter of fractured section, 0.730 inch.
A large number of blowholes in the fractured section, but their size was too small to be measured.
Tenacity per square inch original section, 25,200 pounds.
Tenacity per square inch fractured section, 30,104 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First stress.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 B.—Material: Alloy.—Original mixture: 98.1 Cu, 1.9 Sn.—Analysis: 97.83 Cu 1.92 Sn.—Dimensions: Length, 4⅛″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 4 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 4 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*		*Pounds.*	*Pounds.*	*Inches.*	
7525	9, 450	0. 01	.0025	11, 690	23, 380	0. 40	.1000
100	12, 200	0. 03	.0075	11, 980	23, 960	0. 44	.1100
560	13, 120	0. 04	.0100	Broke 1¾ inches from B end.			
960	13, 980	0. 06	.0150	Fractured section, elliptical diameters 0.717 and 0.730 inch.			
520	15, 040	0. 10	.0250				
0	.....	Set 0. 10	.....	One blowhole, area 0.059 square inch; the rest of the surface free.			
460	15, 720	0. 11	.0275				
920	16, 440	0. 13	.0325	Tenacity per square inch of original section, 23,960 pounds.			
030	17, 860	0. 16	.0400				
270	18, 540	0. 20	.0500	Tenacity per square inch, deducting blowhole, 27,166 pounds.			
875	19, 750	0. 24	.0600				
610	21, 220	0. 30	.0750	Tenacity per square inch in fractured section, 29,142 pounds.			
250	22, 500	0. 35	.0875				

TABLE LV.—ALLOY OF COPPER AND TIN.

Original mark: No. 3 A.—Material: Alloy.—Original mixture: 96.27 Cu, 3.73 Sn.—Analysis: 96.16 Cu, 3.71 Sn.—Dimensions: Length, 6″. Diameter, 0.79″.

Load.	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*		*Pounds.*	*Pounds.*	*Inches.*	
6, 000	12, 000	0. 01	.0017	15, 200	30, 400	0. 70	.1167
7, 850	15, 700	0. 02	.0033	15, 480	30, 960	0. 79	.1317
9, 200	18, 400	0. 06	.0100				
9, 850	19, 700	0. 10	.0167	Broke 1½ inches from C end.			
0	.....	Set 0. 09	.....	Diameter of fractured section, 0.696 inch.			
11, 000	22, 000	0. 18	.0300				
11, 580	23, 160	0. 24	.0400	One blowhole in center of specimen, extending through about 3 inches of its length. Area of blowhole at fractured section, 0.076 square inch.			
12, 000	24, 000	0. 29	.0483				
12, 530	25, 060	0. 36	.0600	Tenacity per square inch original section, 30,960 pounds.			
13, 150	26, 300	0. 40	.0667				
1 m.	.....	0. 45	.0750	Tenacity per square inch, deducting blowhole, 36,509 pounds.			
13, 780	27, 560	0. 48	.0800				
14, 150	28, 300	0. 54	.0900	Tenacity per square inch fractured section, 40,697 pounds.			
14, 650	29, 300	0. 61	.1017				

TABLE LVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 3 B.—Material: Alloy.—Original mixture: 96.27 Cu, 3.73 Sn.—Analysis: 95.96 Cu, 3.89 Sn.—Dimensions: Length, 5½″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*		*Pounds.*	*Pounds.*	*Inches.*	
6, 050	12, 100	0. 01	.0020	16, 400	32, 800	0. 66	.1360
8, 120	16, 240	0. 03	.0060	16, 520	33, 040	0. 77	.1540
10, 000	20, 000	0. 05	.0100				
0	.....	Set 0. 04	.....	Broke in middle.			
10, 850	21, 700	0. 08	.0166	Diameter of fractured section, 0.696 inch.			
11, 550	23, 100	0. 12	.0240	Two blowholes in surface of fracture. Area, 0.0095 square inch.			
12, 340	24, 680	0. 19	.0380				
12, 950	25, 900	0. 24	.0480	Tenacity per square inch original section, 33,040 pounds.			
13, 450	26, 900	0. 30	.0600				
13, 880	27, 760	0. 34	.0680	Tenacity per square inch, deducting blowholes, 33,112 pounds.			
14, 440	28, 880	0. 39	.0780				
15, 000	30, 000	0. 48	.0960	Tenacity per square inch fractured section, 44,696 pounds.			
15, 500	31, 000	0. 57	.1140				
16, 000	32, 000	0. 62	.1240				

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 4 A.—Material: Alloy.—Original mixture: 92.8 Cu, 7.2 Sn.—Analysis, 7.84 Sn.—Dimensions: Length, 5". Diameter, 0.798".

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
5,100	10,200	0.01	.0020
8,000	16,000	0.02	.0040
10,000	20,000	0.03	.0060
10,760	21,520	0.05	.0100
11,410	22,820	0.09	.0180
0	.....	Set 0.08	.....
11,900	23,800	0.11	.0220
12,800	25,600	0.14	.0280
13,140	26,280	0.21	.0420
14,000	28,000	0.27	.0540
14,610	29,220	0.37	
14,650	29,300	0.39	

Broke 1¼ inches from C end.
Diameter of fractured section, 0.739
blowholes.
Tenacity per square inch of origin
29,300 pounds.
Tenacity per square inch in fractu
35,012 pounds.

TABLE LVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 4 B.—Material: Alloy.—Original mixture: 92.8 Cu, 7.2 Sn.—Dimensio
5¼". Diameter, 0.798".

Load.	Load per square inch.	Elongation in 5.23 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
8,000	16,000	0.01	.0019
10,000	20,000	0.02	.0039
11,000	22,000	0.03	.0057
11,700	23,400	0.05	.0096
12,000	24,000	0.07	.0034
0	.....	Set 0.06	.....
12,500	25,000	0.09	.0172
13,680	27,360	0.16	.0306
13,890	27,780	0.17	.0325

Broke 1¾ inches from D end.
Diameter of fractured section, 0.73
blowholes.
Tenacity per square inch of origi
27,780 pounds.
Tenacity per square inch in fractu
32,559 pounds.

TABLE LIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 5 A.—Material: Alloy.—Original mixture: 90 Cu, 10 Sn.—Analysis 9.66 Sn.—Dimensions: Length, 3.4". Diameter: 0.796".

Load.	Load per square inch.	Elongation in 3.4 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
4,700	9,400	0.01	.0029
7,640	15,280	0.02	.0059
12,340	24,680	0.06	.0176
12,760	25,520	0.10	.0294
13,260	26,520	0.13	.0384
13,360	26,720	0.14	.0412

Broke 1½ inches from C end.
Diameter of fractured section, 0.745
A few very small blowholes.
Tenacity per square inch in origi
26,720 pounds.
Tenacity per square inch in fractu
30,649 pounds.

TABLE LX.—ALLOY OF COPPER AND TIN.

Original mark: No. 5 B.—Material: Alloy.—Original mixture: 90 Cu, 10 Sn.—Analysis 9.50 Sn.—Dimensions: Length, 3.45". Diameter: 0.798".

Load.	Load per square inch.	Elongation in 3.45 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
8,220	16,440	0.01	.0029
10,300	20,600	0.03	.0087
11,075	22,150	0.06	.0174
12,000	24,000	0.07	.0203
12,680	25,360	0.09	.0261
0	.....	Set 0.08	.....
13,250	26,500	0.11	.0319
13,500	27,000	.....	.....

Broke at B end.
Diameter of fractured section, 0.76
blowholes.
Tenacity per square inch in origi
27,000 pounds.
Tenacity per square inch in fractu
29,761 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXI.—ALLOY OF COPPER AND TIN.

l mark: No. 6 A.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis: 87.15 Cu, 12.69 Sn.—Dimensions: Length, 4⅞″. Diameter: 0.798″.

Load per square inch.	Elongation in 4.87 inches.	Elongation in parts of original length.
Pounds.	*Inches.*	
20,000	0.01	.0020
24,000	0.03	.0062
26,400	0.06	.0123
26,700	0.09	.0185

Broke ¼ inch from C end.
Diameter of fractured section, 0.792 inch.
One blowhole, elliptical, 0.18 x 0.06 inch diameters.
Tenacity per square inch original section, 26,700 pounds.
Tenacity per square inch deducting blowhole, 27,162 pounds.
Tenacity per square inch fractured section, 27,098 pounds.

TABLE LXII.—ALLOY OF COPPER AND TIN.

l mark: No. 6 B.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis: 87.15 Cu, 12.77 Sn.—Dimensions: Length, 5¼″. Diameter: 0.798″.

Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Inches.*	
14,000	0.01	.0060
21,600	0.02	.0040
22,000	0.03	.0060
23,600	0.04	.0080
26,100	0.06	.0120
27,000	0.09	.0180
.....	Set 0.08	.....
28,000	0.11	.0220
29,400	0.14	.0280
30,000	0.18	.0360
.....	Set 0.17	.....

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
15,580	31,160	0.21	.0420
16,000	32,000	0.24	.0480
16,080	33,160	.....	.....

Broke 1 inch from D end.
Diameter of fractured section, 0.773 inch. No blowholes.
Tenacity per square inch original section, 32,160 pounds.
Tenacity per square inch fractured section, 34,263 pounds.

TABLE LXIII.—ALLOY OF COPPER AND TIN.

l mark: No. 7 A.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.99 Cu, 18.92 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

)	19,700	0.01	.002
)	28,000	0.02	.004
)	33,600	Broke in middle.	

eter of fractured section, 0.798 inch.
lowhole, irregular-shaped, about 0.10 inch r.

Tenacity per square inch original section, 33,600 pounds.
Tenacity per square inch, deducting blowhole, 34,139 pounds.

TABLE LXIV.—ALLOY OF COPPER AND TIN.

l mark: No. 7 B.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.99 Cu, 18.75 Sn.—Dimensions: Length, 4¼″. Diameter, 0.798″.

)	20,000	0.01	.002
)	30,280	0.02	.004
)	32,360	Broke at D end, at the fillet.	

Diameter of fractured section, 0.800 inch.
Tenacity per square inch original section, 32,360 pounds.

TABLE LXV.—ALLOY OF COPPER AND TIN.

l mark: No. 8 A.—Material: Alloy.—Original mixture: 76.32 Cu, 23.68 Sn.—Analysis: 76.67 Cu, 23.24 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

s at 10,300 pounds at A end.
tation just perceptible to touch of callipers.
al small blowholes. Area about 0.016 square

Tenacity per square inch original section, 29,053 pounds.
Tenacity per square inch, deducting blowholes 21,281 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 8 B.—Material: Alloy.—Original mixture: 76.32 Cu, 23.68 Sn.—Analysis: 76.40 Cu, 23.23 Sn.—Dimensions: Length, 4⅛″. Diameter, 0.798″.

Broke at 11,710 pounds, ½ inch from D end. No elongation that could be detected.	Tenacity per square inch original section, 23,629 pounds.

TABLE LXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 9 A.—Material: Alloy.—Original mixture: 70 Cu, 30 Sn.—Analysis: 69.90 Cu, 29.85 Sn.—Dimensions: Length of turned portion, 1″. Diameter, 0.985″.

Had difficulty in setting the piece in the jaws of the tensile machine, as the alloy was harder than the steel faces of the jaws. At 2,600 pounds stress the piece slipped out from the jaws, and again at 4,300 and 1,420 pounds. Reset each time. At 6,950 pounds the piece broke in the square portion, 1 inch from the A end of the turned part.	Measurement of fractured section, 1 inch x 0.999 inch. Tenacity of section fractured, per square inch, 7,006 pounds. Tenacity of circular section (unbroken), 9,121 pounds *plus*.

TABLE LXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 9 B.—Material: Alloy.—Original mixture: 70 Cu, 30 Sn.—Analysis: 69.77 Cu, 29.92 Sn.—Dimensions: Length, 1″. Diameter, 0.972″.

Broke in turned portion, at 3,090 pounds.	Tenacity per square inch, 4,164 pounds.

TABLE LXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 10 B.—Material: Alloy.—Original mixture, 68.25 Cu, 31.75 Sn.—Analysis, 68.57 Cu, 31.30 Sn.—Dimensions: Rectangular section, 0.994 x 1.005″. (Too brittle to be turned in lathe.)

Slipped from the jaws of the tensile machine at 500, 650, and 775 pounds. Broke at 1,620 pounds, in the jaws, ¾ inch from end of piece marked D. The piece remaining after this test was too short to be tested further in the same machine, and it was sent to Messrs. Riéhlé Bros., Philadelphia, who tested it, and reported its strength at 1,600 pounds per square inch.	Tenacity per square inch, 1,620 pounds.

TABLE LXX.—ALLOY OF COPPER AND TIN

Original mark: No. 11 A.—Material: Alloy.—Original mixture: 65 Cu, 35 Sn.—Analysis: 65.31 Cu, 34.47 Sn.—Dimensions: Length, 1″. Diameter, 0.974″.

Broke in middle, at 1,770 pounds.	Tenacity per square inch, 2,376 pounds.

TABLE LXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 11 B.—Material: Alloy.—Original mixture: 65 Cu, 35 Sn.—Analysis: 65.36 Cu, 34.47 Sn.—Dimensions: Length, 1″. Diameter, 0.975″.

Slipped from jaws of tensile machine, at 1,520, 1,680 and 1,775 pounds. Broke at 2,025 pounds, in the jaws, ¾ inch from D end, and in the square portion of the specimen.	Tenacity of fractured section per square inch, 2,025 pounds. Tenacity of turned portion (unbroken), 2,712 pounds *plus*.

TABLE LXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 12 A.—Material: Alloy.—Original mixture: 61.71 Cu, 38.29 Sn.—Dimensions: Rectangular section, 0.998″ x 1.004″. (Too brittle to be turned.)

The piece 12 A broke in handling into two pieces, marked A and C. These were sent to Messrs. Riéhlé Bros., Philadelphia, who reported their tenacity to be—	No. 12 A, 250 pounds per square inch. No. 12 C, 1,125 pounds per square inch. No. 12 B broke into several pieces while being turned in the lathe.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXXIII.—ALLOY OF COPPER AND TIN.

ginal mark: No. 13 A.—Material: Alloy.—Original mixture: 56.32 Cu, 43.68 Sn.—Analysis: 56.58 Cu, 3.11 Sn.—Dimensions: Length, 1″. Diameter, 0.980″.

roke at 950 pounds at C end of turned portion.	Tenacity per square inch, 1,259 pounds.

TABLE LXXIV.—ALLOY OF COPPER AND TIN.

ginal mark: No. 13 B.—Material: Alloy.—Original mixture: 56.32 Cu, 43.68 Sn.—Analysis: 56.82 Cu, 43.22 Sn.—Dimensions: Length, 1″. Diameter, 0.975″.

roke at 240 pounds, in the square portion of the imen, 1 inch from the D end of the turned t. ent the larger piece remaining to Messrs.	Riehlé Bros., who reported its strength to be 1,650 pounds per square inch, breaking in the turned portion, near the shoulder.

TABLE LXXV.—ALLOY OF COPPER AND TIN.

ginal mark: No. 14 A.—Material: Alloy.—Original mixture: 51.8 Cu, 48.2 Sn.—Analysis: 62.27 Cu, 37.58 Sn.—Dimensions: Length, 1″. Diameter, 0.968″.

roke in jaws of machine, in the square portion, ch from C end, at 1,170 pounds. enacity of section fractured, 1,170 pounds per are inch.	Tenacity of turned portion (unbroken), 1,590 pounds *plus*.

TABLE LXXVI.—ALLOY OF COPPER AND TIN.

ginal mark: No. 14 B.—Material: Alloy.—Original mixture: 51.8 Cu, 48.2 Sn.—Analysis: 38.41 Cu, 61.04 Sn.—Dimensions: Length, 1″. Diameter, 0.792″.

roke at 1,970 pounds in middle of turned por- n.	Tenacity per square inch, 3,940 pounds.

TABLE LXXVII.—ALLOY OF COPPER AND TIN.

ginal mark: No. 15 A.—Material: Alloy.—Original mixture: 47.95 Cu, 52.05 Sn.—Analysis: 47.72 Cu, 51.99 Sn.—Dimensions: Section, 1.005″ square.

he piece No. 15 A broke into two pieces in dling. he broken pieces, marked A and C, were sent	to Messrs. Riehlé Bros., who reported their tenacity to be— No. 15 A, 900 pounds per square inch. No. 15 C, 2,100 pounds.

TABLE LXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 15 B.—Material: Alloy.—Analysis: 47.49 Cu, 52.29 Sn.

his piece broke in the lathe while being turned.	Pieces too short for test.

TABLE LXXIX.—ALLOY OF COPPER AND TIN.

ginal mark: No. 16 A.—Material: Alloy.—Original mixture: 44.63 Cu, 55.37 Sn.—Analysis: 44.62 Cu, 55.15 Sn.—Dimensions: Length, 1″. Diameter, 0.980″.

roke at 2,620 pounds in middle of turned part.	Tenacity per square inch, 3,466 pounds.

TABLE LXXX.—ALLOY OF COPPER AND TIN.

ginal mark: No. 16 B.—Material: Alloy.—Analysis: 44.42 Cu, 55.41 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 1,280, after the stress had been applied several seconds, at D end of turned part.	Elongation just perceptible to touch of calipers.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 A.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 45.93 Cu, 53.80 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 1,130 pounds ¼ inch from A end. No elongation detected.	Tenacity per square inch, 2,260 pounds.

TABLE LXXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 B.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 38.83 Cu, 60.79 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 2,780 pounds ¼ inch from B end. No elongation.	Tenacity per square inch, 5,560 pounds.

TABLE LXXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 A.—Material: Alloy.—Original mixture: 39.20 Cu, 60.80 Sn.—Analysis (No. 18 C): 38.37 Cu, 61.32 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke in the tensile-machine before strain was applied, with the weight of the piston and attachments, about 100 pounds.	Tenacity doubtful.

TABLE LXXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 B.—Material: Alloy.—Analysis (No. 18 C), 38.37 Cu, 61.32 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 1,410 pounds 2¼ inches from B end. Elliptical-shaped blowhole in fractured surface. Area, 0.12 square inch.	Tenacity per square inch, 2,820 pounds. Tenacity per square inch, deducting blowhole, 3,711 pounds.

TABLE LXXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 A.—Material: Alloy.—Original mixture: 34.95 Cu, 65.05 Sn.—Analysis (No. 19 C): 34.22 Cu, 65.80 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke 1 inch from A end in the same manner as No. 18 A.	Tenacity, doubtful.

TABLE LXXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 B.—Material: Alloy.—Analysis (No. 19 C): 34.22 Cu, 65.80 Sn.—Dimensions: Length, 6″. Diameter, 0.799″.

Broke 1 inch from D end at 1,690 pounds.	Tenacity per square inch, 3,371 pounds.

TABLE LXXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 20 A.—Material: Alloy.—Original mixture: 28.72 Cu, 71.28 Sn.—Analysis, 26.92 Cu, 73.08 Sn.—Dimensions: Length, 6″. Diameter, 0.799″.

Broke at 900 pounds 2 inches from C end.	Tenacity per square inch, 1,795 pounds.

TABLE LXXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 20 B.—Material: Alloy.—Original mixture: 28.72 Cu, 71.28 Sn.—Analysis, 25.12 Cu, 74.51 Sn.—Dimensions: Length, 6″. Diameter, 0.799″.

Broke at 750 pounds at D end.	Tenacity per square inch, 1,500 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE LXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 21 A.—Material: Alloy.—Original mixture: 24.38 Cu, 75.62 Sn.—Analysis: 22.80 Cu, 76.89 Sn.—Dimensions: Rectangular section, 0.997″ x 1.007″.

Bar No. 21 contained a blowhole which extended roughout nearly its whole length. The tension-eces were therefore left of the original rectangu-r section. 21 A broke at 6,300 pounds 1½ inches from C d. Elongation, 0.01 inch in 6 inches. Tenacity per square inch of *total* original sec-on 6,275 pounds.	The blowhole at the fractured surface was ellip-tical in section, measuring 0.21 x 0.18 inch in diam-eter. The distances of the edges of the hole from the two nearest edges of the fractured surface were 0.27 and 0.36 inch. Area of blowhole, 0.0297 inch. Tenacity per square inch of metal actually frac-tured, 6,493 pounds.

TABLE XC.—ALLOY OF COPPER AND TIN.

Original mark: No. 21 B.—Material: Alloy.—Original mixture: 24.38 Cu, 75.62 Sn.—Analysis, 23.89 Cu, 75.68 Sn.—Dimensions: Rectangular section, 1,000″ x 1,020″.

Broke at 7,420 pounds 3 inches from B end. No elongation. Size of blowhole, 0.30 x 0.21 inch, liptical. Area, 0.0495 inch. Position of blow-ole, 0.25 inch and 0.30 inch from nearest edges.	Tenacity per square inch of metal actually frac-tured, 7,646 pounds. Tenacity per square inch of total original sec-tion, 7,275 pounds.

TABLE XCI.—ALLOY OF COPPER AND TIN.

Original mark: No. 22 A.—Material: Alloy.—Original mixture: 21.18 Cu, 78.82 Sn.—Analysis: 20.28 Cu, 79.64 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 3,220 pounds at A end. No elongation detected.	Tenacity per square inch, 6,440 pounds.

TABLE XCII.—ALLOY OF COPPER AND TIN.

Original mark: No. 22 B.—Material: Alloy.—Original mixture: 21.18 Cu, 78.82 Sn.—Analysis, 20.21 Cu, 79.62 Sn.—Dimensions: Length, 6″. Diameter, 0.799″.

Broke at 1,120 pounds ½ inch from D end. No elongation detected.	Tenacity per square inch, 2,234 pounds.

TABLE XCIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 23 A.—Material: Alloy.—Original mixture: 15.19 Cu, 84.81 Sn.—Analysis, 15.12 Cu, 84.58 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Broke at 275 pounds ½ inch from C end. No elongation.	Tenacity per square inch, 550 pounds.

TABLE XCIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 23 B.—Material: Alloy.—Original mixture: 15.19 Cu, 84.81 Sn.—Analysis, 15.04 Cu, 84.65 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	
Pounds.	*Pounds.*	*Inches.*		Broke at D end. Diameter of fractured section, 0.798 inch. Tenacity per square inch, original section, 6,520 pounds.
2,700	5,400	0.01	.002	
3,260	6,520	0.02	.004	

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING. STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XCV.—ALLOY OF COPPER AND TIN.

Original mark: No. 24 A.—Material: Alloy.—Original mixture: 11.84 Cu, 88.16 Sn.—Analysis: 11.49 Cu, 88.44 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,650	3,300	0.01	.0020
2,760	5,520	0.04	.0080
3,260	6,520	0.06	.0120
3,300	6,600	0.10	.0200
0	----------	Set 0.10	----------
3,300	6,600	0.13	.0260
In 2 m.	6,600	0.37	.0740

Broke 2 inches from A end.
Fractured section elliptical; diameters, 0.768 and 0.776 inch.
Tenacity per square inch original section, 6,650 pounds.
Tenacity per square inch fractured section, 7,050 pounds.

TABLE XCVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 24 B.—Material: Alloy.—Original mixture: 11.84 Cu, 88.16 Sn.—Analysis: 11.48 Cu, 88.50 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5.02 inches.	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
1,820	3,640	0.01	.002
2,680	5,360	0.02	.004
3,080	6,160	0.04	.008

Broke ⅝ inch from B end.
Diameter of fractured section, 0.795 inch.
Tenacity per square inch original section, 6,160 pounds.
Tenacity per square inch fractured section, 6,394 pounds.

TABLE XCVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 A.—Material: Alloy.—Original mixture: 9.7 Cu, 90.3 Sn.—Analysis: 8.82 Cu, 91.12 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.
Pounds	*Pounds.*	*Inches.*	
1,520	3,040	0.01	.0017
2,200	4,400	0.02	.0033
2,520	5,040	0.04	.0067
2,830	5,660	0.07	.0117
3,000	6,000	0.11	.0184
In 2 m.	6,000	0.43	.0714

Broke 2½ inches from C end.
Diameter of fractured section, 0.730 inch.
Tenacity per square inch original section, 6,084 pounds.
Tenacity per square inch fractured section, 7,167 pounds.

TABLE XCVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 B.—Material: Alloy.—Analysis: 8.32 Cu, 91.66 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 5 inches	Elongation in parts of original length.
Pounds.	*Pounds.*	*Inches.*	
2,000	4,000	0.01	.0020
2,700	5,400	0.03	.0060
2,910	5,820	0.05	.0100
3,450	6,900	0.12	.0240
In 1 m.	6,900	0.33	.0660

Broke 1 inch from D end.
Diameter of fractured section, 0.740 inch.
Tenacity per square inch original section, 6,900 pounds.
Tenacity per square inch fractured section, 8,021 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE XCIX.—ALLOY OF COPPER AND TIN.

nal mark: No. 26 A.—Material: Alloy.—Original mixture: 4.29 Cu, 95.71 Sn.—Analysis: 3.70 Cu, 96.30 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

	Load per square inch.	Elongation in 6 inches.	Elongation in parts of original length.	
ds.	*Pounds.*	*Inches.*		Broke in middle. Diameter of fractured section, 0.680 inch. Blowhole 0.25 inch diameter in fractured surface. Tenacity per square inch original section, 4,300 pounds. Tenacity per square inch, deducting blowholes, 4,767 pounds. Tenacity per square inch fractured section, 5,920 pounds.
0	2,600	0.01	.0017	
0	3,060	0.04	.0067	
0	3,700	0.10	.0167	
0	4,000	0.16	.0267	
0	4,300	0.19	.0333	
m.	4,300	0.59	.0983	

TABLE C.—ALLOY OF COPPER AND TIN.

nal mark: No. 26 B.—Material: Alloy.—Analysis: 3.74 Cu, 96.32 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	
ds.	*Pounds.*	*Inches.*		Broke in middle. Diameter of fractured section, 0.660 inch. Breaking load, 2,630 pounds. Tenacity per square inch original section, 5,260 pounds. Tenacity per square inch fractured section, 7,687 pounds, (assuming that the final section sustained the maximum load of 2,630 pounds.)
0	3,100	0.01	.002	
0	4,000	0.03	.006	
0	5,260	0.09	.018	
m.	5,260	0.62	.124	
ced to—				
0	3,600	0.64	.128	
m.	3,600	0.65	.130	
m.	3,600	0.74	.148	

TABLE CI.—ALLOY OF COPPER AND TIN.

nal mark: No. 27 A.—Material: Alloy.—Original mixture: 1.11 Cu, 98.89 Sn.—Analysis: 0.75 Cu, 98.89 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

	Load per square inch.	Elongation in 5.01 inches.	Elongation in parts of original length.	
ds	*Pounds.*	*Inches.*		Broke in middle. Diameter of fractured section, 0.550 inch. Surface very much corrugated by strain. Tenacity per square inch original section, 3,600 pounds. Tenacity per square inch fractured section (assuming that the final section sustained the load of 1,800 pounds), 7,576 pounds.
0	3,200	0.09	.018	
m.	3,200	0.18	.036	
0	3,600	0.24	.048	
m.	3,600	0.40	.080	
m.	3,600	0.65	.013	
m.	3,600	1.26	.252	
m.	3,600	1.58	.316	

TABLE CII.—ALLOY OF COPPER AND TIN.

nal mark: No. 27 B.—Material: Alloy.—Original mixture: 1.11 Cu, 98.89 Sn.—Analysis: 0.72 Cu, 99.06 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

	Load per square inch.	Elongation in 5.08 inches.	Elongation in parts of original length.	
ds.	*Pounds.*	*Inches.*		Broke 2 inches from B end. Diameter of fractured section, 0.540 inch. Tenacity per square inch original section, 3,700 pounds. Tenacity per square inch fractured section, 8,157 pounds.(*l*)
0	3,100	0.13	.0224	
m.	3,100	0.17	.0293	
0	3,700	0.28	.0483	
m.	3,700	0.72	.1241	
0	.....	Set. 0.72	.....	
0	3,700	0.81	.1397	

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TEC

TABLE CIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 A.—Material: Alloy.—Original mixture: 0.557 Cu, 99.443 Sn.—An Cu, 99.46 Sn.—Dimensions: Length, 6″. Diameter, 0.799″.

Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	
Pounds.	*Pounds.*	*Inches.*		Broke in middle; greatest stress 23
1,400	2,800	0.02	.004	Diameter of fractured section 0.455
1,700	3,400	0.05	.0083	Surface very much distorted.
1,880	3,760	0.25	.05	Tenacity per square inch original s
2,350	4,700	Extending rapidly; measurement not taken.		pounds.
Reduced to—				Tenacity per square inch fra tured
2,200	4,400	1.80	.36	suming that the final section sustains mum load of 2,350 pounds; plainly this case), 14,453 pounds.

TABLE CIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 B.—Material: Alloy.—Original mixture: 0.557 Cu, 99.443 Sn.—Analy 99.4 Sn.—Dimensions: Length, 6″. Diameter, 0.798″.

Load.	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.	
Pounds.	*Inches.*	*Pounds.*		Broke in middle.
1,250	2,500	0.01	.0017	Diameter of fractured section, 0.475
In 3 m.	2,500	0.03	.0050	Tenacity per square inch original
1,500	3,000	0.08	.0133	pounds.
In 3 m.	3,000	0.30	.0498	Tenacity per square inch fracture
In 8 m.	3,000	0.50	.0831	suming that the final section sustai
Increased strain rapidly to—				of 2,125 pounds), 11,992 pounds.
2,125	4,250	1.93	.3206	
Reduced to—				
1,400	2,800	2.10	.3488	

TABLE CV.—CAST TIN.

Original mark: No. 29 A.—Material: Banca tin.—Dimensions: Length, 6″. Diameter

Load.	Load per square inch.	Elongation in 6 inches	Elongation in parts of original length.	
Pounds	*Pounds.*	*Inches.*		Broke ½ inch from A end
1,700	3,400	0.15	.025	Diameter of fractured section 0.490 i
0	.....	Set 0.15	.025	mately). The section was very irre
Reduced to—				and an exact measurement could not
1,250	2,500	0.19	.0318	Tenacity per square inch of origi
In 2 m.	2,500	0.27	.045	considering 1,400 pounds as the br
1,400	2,800	0.32	.0533	2,800 pounds (with gradual test).
In 10 m.	2,800	1.70	.2833	

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*First series.*]

MANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CVI.—CAST TIN.

ginal mark: No. 29 B.—Material: Banca tin —Dimensions: Length, 6″. Diamete., 0.798″.

	Load per square inch.	Elongation in 6.02 inches.	Elongation in parts of original length.	
	Pounds.	*Inches.*		
	1, 950	0. 01	. 0017	Broke 2 inches from D end.
	2, 360	0. 03	. 0050	Fractured section very irregular, and drawn out almost to a point. Estimated diameter of final section 0.300 inch.
	2, 580	0. 09	. 0150	
	3, 200	0. 20	. 0332	Tenacity per square inch of original section (*with rapid test*) 4.200 pounds.
	4, 000	0. 58	. 0963	
	4, 200	1. 88	. 3123	
oe extending rapidly and srtain reduced to—				
	3, 400	2. 58	. 4269	

TABLE CVII.—CAST COPPER.

l mark: No. 30 A.—Material: Lake Superior copper, cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.	Load.	Load per square inch.	Elongation in 5 inches.	Elongation in parts of original length.
	Pounds.	*Inches.*		*Pounds.*	*Pounds.*	*Inches.*	
	800	0. 0004	. 00008	11, 000	22, 000	0. 1605	. 03210
	2, 000	0. 0011	. 00022	12, 200	24, 400	0. 2191	. 04382
	4, 000	0. 0022	. 00044	14, 000	28, 000	0. 3258	. 06516
	8, 000	0. 0027	. 00054	270	540	Set 0. 3155	.....
	12, 000	0. 0032	. 00064	14, 400	28, 800	0. 3448	. 06896
	12, 800	0. 0052	. 00104	14, 600	29, 200	0. 3760	. 07520
	13, 600	0. 0083	. 00166	Broke just as reading was taken ¼ inch from A end. Fractured section distorted from circular form. Three diameters measured 0.737 inch, 0.725 inch, and 0.732 inch.			
	14, 400	0. 0132	. 00264				
	16, 000	0. 0358	. 00716				
	17, 600	0. 0642	. 01284				
	19, 200	0. 0942	. 01884	Tenacity per square inch original section, 29,200 pounds.			
	19, 600	0. 1073	. 02146				
	500	Set 0. 0951	.....	Tenacity per square inch fractured section, 34,790 pounds.			
	20, 400	0. 1218	. 02436				

TABLE CVIII.—CAST COPPER.

ginal mark: No. 30 B.—Material: Cast copper.—Dimensions: Length, 5″. Diameter, 0.798″.

	Load per square inch.	Elongation in 5 inches.	Compression in parts of original length.	Load.	Load per square inch.	Elongation in 5 inches.	Compression in parts of original length.
	Pounds.	*Inches.*		*Pounds*	*Pounds.*	*Inches.*	
	12, 800	0. 0035	. 00070	12, 600	25, 200	0. 2437	. 04874
	14, 000	0. 0081	. 00162	13, 000	26, 000	0. 2707	. 05414
	14, 400	0. 0111	. 00222	13, 200	26, 400	.....	.....
	15, 600	0. 0259	. 00518				
	16, 800	0. 0439	. 00878	Broke in middle just as beam rose.			
	18, 000	0. 0652	. 01304	Fractured section, elliptical. Diameters, 0.752 and 0.740 inch.			
	18, 800	0. 0807	. 01614				
	19, 600	0. 0952	. 01904	Tenacity per square inch original section, 26,400 pounds.			
	20, 400	0. 1147	. 02294				
	21, 200	0. 1317	. 02634	Tenacity per square inch fractured section, 30,201 pounds.			
	22, 000	0. 1517	. 03034				
	22, 800	0. 1707	. 03414	NOTE.—The piece bent slightly under strains less than 6,400 pounds, and thus caused errors in the readings of elongations below that point.			
	23, 600	0. 1967	. 03934				
	24, 400	0. 2182	. 04364				

RECORD OF TESTS BY COMPRESSIVE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CIX.—CAST COPPER.

Original mark: No. 1.—Material: Lake Superior copper.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.0029	3,259	.00145	15,000	0.368	48,892	.1840
1,500	0.0087	4,889	.00435	16,250	0.426	52,967	.2130
2,000	0.015	6,519	.0075	17,000	0.477	55,411	.2385
3,000	0.022	9,778	.0110	18,000	0.528	58,671	.2640
4,000	0.030	13,038	.0150	18,925	0.584	61,688	.2920
5,000	0.043	16,297	.0215	19,600	0.633	63,886	.3165
6,000	0.065	19,557	.0325	20,500	0.707	66,820	.3535
7,000	0.079	22,816	.0395	22,000	0.838	71,709	.4190
8,000	0.097	26,076	.0485	23,000	0.896	74,968	.4480
9,000	0.128	29,335	.0640				
10,000	0.153	32,595	.0765	Piece removed bent.			
11,000	0.182	35,854	.0910	Piece slightly bent at 9,000 pounds. After 17,000 pounds the beam dropped immediately after the strain was applied.			
12,000	0.209	39,114	.1045				
13,000	0.251	42,373	.1255				
14,000	0.304	45,633	.1520				

TABLE CX.—CAST COPPFR.

Original mark: No. 1 D.—Material: Cast copper.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000			18,000	.4115	58,671	.2057
4,000	.0025	13,038	.00125	20,000	.5049	65,188	.2624
6,000	.0233	19,557	.0116	22,000	.7018	71,709	.3509
8,000	.0538	26,075	.0269	24,000	.8678	78,228	.4339
10,000	.0908	32,595	.0454	25,000			
12,000	.1271	39,114	.0635				
14,000	.2073	45,633	.1036	Lifted the beam.			
16,000	.2924	52,152	.1462				

TABLE CXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 2 D.—Material: Alloy.—Original mixture: 98.1 Cu, 1.9 Sn.—Analysis 97.83 Cu, 1.9 Sn.—Dimensions: Length 2″. Diameter, 0.625″.

500	0.005	1,630	.0025	13,000	0.327	42,373	.1635
1 000	0.009	3,259	.0045	14,000	0.386	45,633	.1930
2,000	0 015	6,519	.0075	14,500	0.480	46,263	.2400
3,000	0 021	9,778	.0105	Reduced to—			
4,000	0.026	13,038	.0130	14,000	0.538	45,633	.2690
5,000	0.028	16,297	.0140	13,000	0.590	42,373	.2950
6,000	0.032	19,557	.0160	10,000	0.639	32,595	.3195
7,000	0.038	22,816	.0190	7,000	0.685	22,816	.3425
8,000	0.047	26,076	.0235	2,000	0.736	6,519	.3680
9,000	0.074	29,335	.0370				
Repeated.				Piece removed bent so that it rested on two corners only.			
9,000	0.106	29,335	.0530	The bending of the piece was first observed at 9,000 pounds.			
10,000	0.170	32,595	.0850				
11,000	0.225	35,854	.1125				
12,000	0.267	39,114	.1335				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXII.—ALLOY OF COPPER AND TIN.

mark: No. 3 D.—Material: Alloy.—Original mixture: 96.27 Cu, 3.73 Sn.—Analysis: 95.96 Cu, 3.80 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Inches.	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
0.003	1,630	.0015	Reduced to—			
0.010	6,519	.0050	11,900	0.192	38,788	.0960
0.014	9,778	.0070	12,300	0.255	40,092	.1275
0.020	13,038	.0100	13,000	0.269	42,373	.1345
0.022	16,297	.0110	14,000	0.289	45,633	.1445
0.025	19,557	.0125	15,000	0.313	48,892	.1565
0.027	22,816	.0135	15,600	0.346	50,848	.1730
0.030	26,076	.0150	16,000	0.372	52,152	.1860
0.033	29,335	.0165	Reduced to—			
0.041	32,595	.0205	14,800	0.390	48,241	.1950
0.053	35,854	.0265	10,000	0.539	32,595	.2695
0.069	37,484	.0345	2,000	0.605	6,519	.3025
0.093	39,114	.0465	Piece removed bent in a double curve.			
0.135	40,744	.0675	Bending first observed at 12,500 pounds.			
0.160	42,048	.0800				

TABLE CXIII.—ALLOY OF COPPER AND TIN.

mark: No. 4 B.—Material: Alloy.—Original mixture: 92.8 Cu, 7.2 Sn.—Dimensions: Length 2″. Diameter: 0.625″.

0.005	1,630	.0025	16,000	0.287	52,152	.1435
0.010	3,259	.0050	17,500	0.332	57,041	.1660
0.015	6,519	.0075	19,000	0.370	61,930	.1850
0.020	9,778	.0100	21,000	0.429	68,449	.2145
0.024	13,038	.0120	21,000	0.489	74,968	.2445
0.028	16,297	.0140	25,000	0.537	81,487	.2685
0.031	19,557	.0155	25,800	0.581	84,095	.2905
0.037	22,816	.0175	Strain decreased in 1 min. to—			
0.044	26,076	.0220	25,000	0.702	81,487	.3510
0.062	29,335	.0310	20,000	0.820	65,190	.4100
0.080	30,965	.0400	14,000	0.870	45,633	.4350
0.120	32,595	.0600	2,500	0.907	24,446	.4535
0.140	35,854	.0700	Piece removed bent.			
0.159	39,114	.0795	Bending first observed at 9,000 pounds.			
0.225	45,633	.1125				

TABLE CXIV.—ALLOY OF COPPER AND TIN.

mark: No. 5 D.—Material: Alloy.—Original mixture: 90 Cu, 10 Sn.—Analysis: 90.43 Cu, 9.50 Sn.—Dimensions: Length, 2″. Diameter, 0.625.″

0.007	1,630	.0035	15,600	0.302	50,848	.1510
0.010	3,259	.0050	17,000	0.335	55,411	.1675
0.016	6,519	.0080	18,000	0.366	58,671	.1830
0.022	9,778	.0110	19,000	0.442	61,930	.2210
0.026	13,038	.0130	Reduced to—			
0.030	16,297	.0150	18,800	0.469	61,279	.2345
0.034	19,557	.0170	18,000	0.546	58,671	.2730
0.044	22,816	.0220	16,300	0.579	53,130	.2895
0.059	26,076	.0295	14,500	0.604	47,263	.3020
0.080	29,335	.0400	10,600	0.635	34,551	.3175
0.110	32,595	.0550	4,000	0.671	13,038	.3355
0.154	35,854	.0770	Piece bent and slipped out from between the pressure plates.			
0.231	39,929	.1155				
0.244	44,003	.1220	Bending first observed at 10,000 pounds.			
0.266	47,263	.1330				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXV.—ALLOY OF COPPER AND TIN

Original mark: No. 6 B.—Material: Alloy.—Original mixture: 86.57 Cu, 13.43 Sn.—Analysis, 87.13 Cu, 12.77 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.005	3,259	.0025	22,000	0.337	71,709	.1685
2,000	0.011	6,519	.0055	24,000	0.390	78,228	.1950
4,000	0.018	13,038	.0090	26,000	0.449	84,747	.2245
6,000	0.023	19,557	.0115	27,500	0.496	89,636	.2480
8,000	0.028	26,076	.0140	Decreased to—			
10,000	0.045	32,595	.0225	27,250	0.531	88,821	.2655
11,000	0.066	35,854	.0330	26,100	0.599	85,073	.2995
12,000	0.101	39,114	.0505	24,000	0.665	78,228	.3325
14,000	0.146	45,633	.0730	20,000	0.716	65,190	.3580
16,000	0.197	52,152	.0985	17,000	0.741	55,411	.3705
17,000	0.218	55,411	.1090	10,000	0.772	32,595	.3860
18,000	0.244	58,671	.1220	Piece slipped out from between pressure plates. Bending first observed at 11,000 pounds.			
20,500	0.298	66,820	.1490				

TABLE CXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 7 A.—Material: Alloy.—Original mixture: 80 Cu, 20 Sn.—Analysis: 80.99 Cu, 13.51 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

500	0.006	1,630	.0030	24,000	0.202	78,228	.1010
1,000	0.012	3,259	.0060	26,000	0.215	84,747	.1075
2,000	0.015	6,519	.0075	28,000	0.241	91,266	.1205
3,000	0.020	9,778	.0100	30,000	0.285	97,785	.1425
4,000	0.023	13,038	.0115	31,000	0.298	101,044	.1490
6,000	0.031	10,557	.0155	31,750	0.328	103,489	.1640
8,000	0.038	26,076	.0190	Decreased to—			
10,000	0.044	32,595	.0220	30,600	0.354	99,741	.1770
12,000	0.052	39,114	.0260	29,000	0.390	94,525	.1950
14,000	0.059	45,633	.0295	28,000	0.406	91,266	.2030
16,000	0.069	52,152	.0345	Piece flew out from between pressure plates, a small piece breaking from one corner. Bending first observed at 20,500 pounds.			
18,000	0.082	58,671	.0410				
21,000	0.106	65,190	.0530				
22,000	0.187	71,709	.0935				

TABLE CXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 8 B.—Material: Alloy.—Original mixture: 76.32 Cu, 23.68 Sn.—Analysis: 76.77 Cu, 23.23 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,000	0.003	3,259	.0015	28,000	0.078	91,266	.0390
2,000	0.011	6,519	.0055	30,000	0.090	97,785	.0450
3,000	0.015	9,778	.0075	31,000	0.100	101,044	.0500
4,000	0.020	13,038	.0100	32,000	0.110	104,303	.0550
6,000	0.027	19,557	.0135	33,000	0.132	107,562	.0660
8,000	0.033	26,076	.0165	Reduced to—			
10,000	0.036	32,595	.0180	31,200	0.158	101,696	.0790
12,000	0.039	39,114	.0195	32,000	0.171	104,303	.0855
14,000	0.042	45,633	.0210	33,000	0.173	107,562	.0865
16,000	0.046	52,152	.0230	34,000	0.175	110,822	.0875
18,000	0.050	58,671	.0250	35,000	0.181	114,081	.0905
20,000	0.058	65,190	.0290	Piece broke suddenly diagonally across the middle. One piece flew out from the machine to a distance of 12 feet.			
22,000	0.059	71,709	.0295				
24,000	0.065	78,228	.0325				
26,000	0.073	84,747	.0365				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

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TABLE CXVIII.—ALLOY OF COPPER AND TIN.

mark: No. 9.—Material: Alloy.—Original mixture: 70 Cu, 30 Sn.—Analysis: 69.90 Cu, 29.85 Sn.—Dimensions: Length, 2″. Diameter, 0, 625″.

Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Inches.	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
0. 001	3, 259	.0005	30, 000	0. 055	97, 785	.0275
0. 008	6, 519	.0040	32, 000	0. 056	104, 303	.0280
0. 017	13, 038	.0085	34, 000	0. 058	110, 822	.0290
0. 031	26, 076	.0153	36, 000	0. 059	117, 341	.0295
0. 038	32, 595	.0190	38, 000	0. 060	123, 860	.0300
0. 039	39, 114	.0195	40, 000	0. 063	130, 379	.0315
0. 043	45, 633	.0215	42, 000	0. 065	136, 898	.0325
0. 045	52, 152	.0225	44, 000	0. 068	143, 417	.0340
0. 046	58, 671	.0230	45, 000	0. 070	146, 676	.0350
0. 049	65, 190	.0245	About 30 seconds after the strain was applied the piece broke suddenly with a loud report, and flew into small pieces. The largest piece that could be found was about the size of a pea.			
0. 050	71, 709	.0250				
0. 052	78, 228	.0260				
0. 053	84, 747	.0265				
0. 054	91, 266	.0270				

TABLE CXIX.—ALLOY OF COPPER AND TIN.

mark: No. 11.—Material: Alloy.—Original mixture: 65 Cu, 35 Sn.—Analysis: 65.31 Cu, 34.47 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

0. 006	6, 519	.0030	18, 000	0. 043	58, 671	.0215
0. 011	9, 778	.0055	20, 000	0. 046	65, 190	.0230
0. 020	13, 038	.0100	22, 000	0. 048	71, 709	.0240
0. 023	19, 557	.0115	24, 000	0. 051	78, 228	.0255
0. 025	26, 076	.0125	25, 000	0. 052	81, 487	.0260
0. 030	32, 595	.0150	26, 000	0. 057	84, 747	.0285
0. 034	39, 114	.0170	Piece broke suddenly, several pieces flying off upper end.			
0. 038	45, 633	.0190				
0. 041	52, 152	.0205				

TABLE CXX.—ALLOY OF COPPER AND TIN.

mark: No 12.—Material: Alloy.—Original mixture: 61.71 Cu, 38.29 Sn.—Analysis: 6.—Dimensions: Length, 2″. Diameter, 0.625″.

0. 004	6, 519	.0020	9, 000	0. 031	29, 335	.0155
0. 010	9, 778	.0050	10, 000	0. 032	32, 595	.0160
0. 014	13, 038	.0070	11, 000	0. 033	35, 854	.0165
0. 018	16, 297	.0090	12, 000	0. 035	39, 114	.0175
0. 021	19, 557	.0105	Broke suddenly, splitting open the upper end, with a wedge-shaped piece left in the middle.			
0. 024	22, 816	.0120				
0. 027	26, 076	.0135				

TABLE CXXI.—ALLOY OF COPPER AND TIN.

mark: No. 15.—Material: Alloy.—Original mixture: 47.95 Cu, 52.05 Sn.—Analysis: 47.72 Cu, 51.99 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

0. 002	4, 889	.0010	12, 000	0. 030	39, 114	.0150
0. 006	8, 149	.0030	14, 000	0. 031	45, 633	.0155
0. 011	11. 408	.0055	16, 000	0. 034	52, 152	.0170
0. 015	14, 668	.0075	18, 000	0. 036	58, 671	.0180
0. 017	17, 927	.0085	20, 000	0. 040	65, 190	.0200
0. 018	21, 187	.0090	21, 000	0. 041	68, 449	.0205
0. 021	24, 446	.0105	25, 000	0. 043	81, 487	.0215
0. 025	27, 706	.0125	26, 000	0. 043	84, 747	.....
0. 027	30, 965	.0135	Broke in applying strain.			
0. 029	34, 225	.0145				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

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TABLE CXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 16 B.—Material: Alloy.—Original mixture: 44.63 Cu, 55.37 Sn.—Analysis: 44.63 Cu, 55.15 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
2,000	0.005	6,519	.0010	10,000	0.031	32,595	.0062
3,000	0.010	9,778	.0020	Repeated—			
4,000	0.014	13,038	.0028	10,000	0.033	32,595	.0066
5,000	0.018	16,297	.0036	11,000		35,854	
6,000	0.022	19,557	.0044	Broke in applying strain, a cone-shaped wedge at the top of the piece apparently crushing out the metal on all sides of it.			
7,000	0.025	22,816	.0050				
8,000	0.027	26,076	.0054				
9,000	0.029	29,335	.0058				

TABLE CXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 D.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 38.83 Cu, 60.79 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,000	0.004	3,259	.0020	8,000	0.030	26,076	.0150
2,000	0.009	6,519	.0045	9,000	0.033	29,335	.0165
3,000	0.015	9,778	.0075	10,000	0.035	32,595	.0175
4,000	0.018	13,038	.0090	11,000	0.039	35,854	.0195
5,000	0.021	16,297	.0105	12,000	0.041	39,114	.0205
6,000	0.024	19,557	.0120	Broke just as strain was applied. Conical wedge-shaped fracture, like No. 16 B.			
7,000	0.026	22,816	.0130				

TABLE CXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 17 B.—Material: Alloy.—Original mixture: 41.74 Cu, 58.26 Sn.—Analysis: 38.83 Cu, 60.79 Sn.—Dimensions: Length 2″. Diameter, 0.625″.

2,000	0.004	6,519	.0020	8,000	0.023	26,076	.0115
3,000	0.009	9,778	.0045	9,000	0.025	29,335	.0125
4,000	0.013	13,038	.0065	10,000	0.028	32,595	.0140
5,000	0.017	16,297	.0085	11,000	0.031	35,854	.0155
6,000	0.019	19,557	.0095	12,000	0.034	39,114	.0170
7,000	0.021	22,816	.0105	Broke in applying strain. Fracture like 17 D.			

TABLE CXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 18 D.—Material: Alloy.—Original mixture: 39.2 Cu, 60.8 Sn.—Analysis: 38.37 Cu, 61.32 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,000	0.003	3,259	.0015	7,000	0.027	22,816	.0135
2,000	0.009	6,519	.0045	8,000	0.029	26,076	.0145
3,000	0.014	9,778	.0070	9,000		29,335	
4,000	0.019	13,038	.0095	Broke in applying strain, pieces being crushed off upper end.			
5,000	0.021	16,297	.0105				
6,000	0.024	19,557	.0120				

TABLE CXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 19 B.—Material: Alloy.—Original mixture: 34.95 Cu, 65.05 Sn.—Analysis: 34.22 Cu, 65.80 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

1,000	0.002	3,519	.0010	4,850	0.051	15,809	.0255
2,000	0.006	6,519	.0030	3,200	0.066	10,430	.0330
3,000	0.011	9,778	.0055	2,300	0.096	7,497	.0480
4,000	0.016	13,038	.0080	2,700	0.111	8,801	.0555
5,000	0.020	16,297	.0100	Piece bulged out in the middle. Bulging commenced at 6,000 pounds.			
6,000	0.024	19,557	.0120				
Strain decreased to—							
4,100	0.044	13,364	.0220				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

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TABLE CXXVII.—ALLOY OF COPPER AND TIN.

mark: No. 20 B.—Material: Alloy.—Original mixture: 28.72 Cu, 71.28 Sn.—Analysis: 25.12 Cu, 74.51 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Inches.	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
0.004	4,889	.0020	3,150	0.512	10,267	.2560
0.010	6,519	.0050	3,000	0.561	9,778	.2805
0.018	9,778	.0090				
0.023	13,038	.0115				
0.029	16,297	.0145				
0.034	17,927	.0170				
educed to—						
0.062	14,505	.0310				
0.077	8,801	.0385				
0.088	5,541	.0440				
0.136	2,934	.0680				
0.168	3,259	.0840				
0.194	4,889	.0970				
0.243	6,519	.1215				
0.331	8,149	.1655				
0.458	9,778	.2290				

Removed piece.

At 2,700 pounds (compression 0.077), after the piece had resisted 5,500 pounds, a wedge-shaped piece was observed to be cracked off at the upper corner, but not separated. At 2,000 pounds (compression 0.243) the wedge-shaped piece was crushed out to one side of the compression specimen.

Soon afterwards a second wedge-shaped piece was crushed off from the opposite upper corner, and when the test piece was removed, after a compression of 0.561, both wedges still remained attached to it.

TABLE CXXVIII.—ALLOY OF COPPER AND TIN.

mark: No. 22 B.—Material: Alloy.—Original mixture: 21.18 Cu, 78.82 Sn.—Analysis: 20.21 Cu, 79.62 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

0.011	3,445	.0055	2,500	0.184	8,149	.0920
0.015	3,259	.0075	3,000	0.238	9,778	.1190
0.018	4,889	.0090	3,200	0.274	10,430	.1370
0.022	6,519	.0110	2,500	0.317	8,149	.1585
0.026	9,778	.0130	2,000	0.416	6,519	.0280
0.034	13,038	.0170	1,200	0.503	3,911	.2515
0.047	16,297	.0235	400	0.581	1,304	.2905
ecreased to—						
0.068	15,809	.0340				
0.089	15,646	.0445				
0.101	9,778	.0505				
0.119	10,430	.0595				
0.137	8,638	.0685				
0.167	7,008	.0835				

Piece slipped out from between the pressure-plates. Bent in a double curve with a crack on the convex side of each curve.

Double curve observed at 5,000 pounds. At 4,800 pounds (compression 0.089) the resistance decreased in 2 minutes to 3,300.

TABLE CXXIX.—ALLOY OF COPPER AND TIN.

mark: No. 23 A.—Material: Alloy.—Original mixture: 15.19 Cu, 84.81 Sn.—Analysis: 15.12 Cu, 84.58 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

0.008	2,445	.0040	2,600	0.793	8,475	.3965
0.012	3,259	.0060	2,800	0.914	9,127	.4570
0.015	4,889	.0075	2,900	1.027	9,452	.5135
0.030	6,519	.0150				
0.112	6,519	.0560				
0.260		.1300				
utes strain decreased to—						
0.338	5,215	.1690				
0.417	4,563	.2085				
0.500	4,889	.2500				
0.609	5,541	.3045				
0.706	6,519	.3530				

Removed piece.

At 2,000 pounds (compression 0.112) the piece was slightly bulged out ¼ inch from the bottom.

At 2,900 (compression 1.027) the wedge-shaped pieces separated from the remainder of the specimen.

TABLE CXXX.—ALLOY OF COPPER AND TIN.

mark: No. 24 B.—Material: Alloy.—Original mixture: 11.84 Cu, 88.16 Sn.—Analysis: 11.48 Cu, 88.50 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

0.012	1,630	.0060	Removed piece.
0.020	3,259	.0100	At 3,100 a slight double curve was observed.
0.032	6,519	.0160	At 3,400 the scale-beam dropped instantly if the motion of the handle was stopped, but rose on starting again.
0.059	9,778	.0295	
0.139	10,104	.0695	
0.174	9,778	.0870	When removed, the piece was slightly bent in a double curve and increased in diameter to about 0.85 inch.
0.599	11,082	.2995	
0.857	12,712	.4285	
1.008	14,016	.5040	

RECORDS OF TESTS BY COMPRESSIVE STRESS—Continued.

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TABLE CXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 25 A.—Material: Alloy.—Original mixture: 9.70 Cu, 90.30 Sn.—Analysis: 8.57 Cu, 91.39 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	.....	.....	3,000	Lifted the beam.		
1,000	.0009	3,259	.0004				
2,000	.1117	6,519	.0558	Wedge-shaped pieces cracked at the top and bottom of the specimen, but did not break off.			

TABLE CXXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 26 B.—Material: Alloy.—Original mixture: 4.29 Cu, 95.71 Sn.—Analysis: 3.73 Cu, 96.31 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	.....	.....	2,000	.6845	6,519	.3422
1,000	.0007	3,259	.00035	3,000	Lifted the beam.		

TABLE CXXXIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 27 D.—Material: Alloy.—Original mixture: 1.11 Cu, 98.89 Sn.—Analysis. 0.74 Cu, 99.02 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	.....	.....	2,000	.7264	6,519	.3632
1,000	.0073	3,259	.0036	3,000	.....	.....	.....

TABLE CXXXIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 28 C.—Material: Alloy.—Original mixture: 0.557 Cu, 99.443 Sn.—Analysis: 0.32 Cu, 99.46 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	.....	.....	3,000	Lifted the beam.
1,000	.0038	3,259	.0019		
2,000	.7520	6,519	.3760	Cracked through the middle, but did not separate.	

TABLE CXXXV.—CAST TIN.

Original mark: No. 29 C.—Material: Banca tin, cast in iron mold.—Dimensions: Length, 2″. Diameter 0.625″.

1,250	0.003	4,074	.0015	2,300	0.899	7,497	.4445
1,500	0.012	4,889	.0060				
1,750	0.043	5,704	.0215	Removed piece.			
1,850	0.097	6,030	.0485	At 1,850 pounds the piece was observed to be bulging out on all sides, but still remaining vertical. At the end of the test the piece had a slight bend in one direction, and was increased in diameter to 0.85 and 0.89 inch in different parts of the length.			
1,900	0.158	6,193	.0790				
2,000	0.265	6,519	.1325				
2,100	0.473	6,519	.2365				
2,200	0.612	7,171	.3060				
2,300	0.729	7,497	.3645				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

ECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXXVI.—CAST COPPER.

ıal mark: No. 30.—Material: Lake Superior copper, cast in iron mold.—Dimensions: Length, 2" Diameter, 0.625".

d.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
ds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
00	0.003	1,630	.0015	12,000	0.162	39,114	.0810
00	0.005	3,259	.0025	13,000	0.205	42,373	.1025
00	0.008	6,519	.0040	14,000	0.251	45,633	.1255
00	0.011	9.779	.0055	15,000	0.294	48,892	.1470
00	0.014	13,038	.0070	16,000	0.337	52,152	.1685
00	0.018	16,297	.0090	18,000	0.422	58,671	.2110
00	0.021	19,557	.0105	20,000	0.510	65,190	.2550
00	0.026	22,816	.0130	21,000	0.559	68,449	.2795
00	0.035	26,076	.0175	22,000	0.642	71,709	.3210
00	0.051	29,335	.0255	Piece removed slightly bent.			
00	0.080	32,595	.0400	Surface wrinkled.			
00	0.119	35,854	.0595				

TESTS BY TORSIONAL STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXXXVII.—COPPER AND TIN ALLOYS—1st SERIES.

RESULTS OF TESTS, CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAM.

No.	Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic limit.	Ductility, extension of exterior fiber.	Resilience.	Remarks.
	Sq. in.	*Deg.*	*Ins.*	*Ins.*	*Ft. lbs.*	*Ft. lbs.*		*Ft. lbs.*	
1 A	1.15	49.0	0.40	0.17	57.83	30.82	0.0351	32.85	
1 C	0.86	26.5	0.45	0.20	63.70	34.34	0.0104	22.64	
1 D	1.90	46.0	0.55	0.20	75.46	34.34	0.0310	47.65	
2 A	25.70	296.0	1.08	0.25	137.39	40.22	0.8990	582.78	
2 B	24.30	339.0	1.30	0.20	161.53	34.34	1.1021	562.23	
2 C	11.65	177.0	0.80	0.20	104.81	34.34	0.3890	272.28	Defective; several blowholes.
2 D	10.09	169.0	0.75	0.30	99.04	46.09	0.3600	238.80	Defective; several blowholes.
3 A	42.25	373.0	1.45	0.30	181.15	46.09	1.2669	936.56	
3 B	13.70	168.5	1.00	0.38	128.30	55.50	0.3581	312.69	
3 C	29.50	286.0	1.25	0.40	157.66	57.83	0.8529	658.77	
3 D	22.50	162.0	1.28	0.35	160.60	52.56	0.3344	491.82	
4 A	17.74	166.0	1.40	0.35	175.28	51.96	0.3490	395.03	
4 B	13.22	136.0	1.40	0.35	175.28	51.96	0.2451	296.70	
4 C	8.10	10.0	1.10	0.53	140.04	71.94	0.1140	183.05	
4 D	10.40	110.5	1.18	0.50	149.45	69.58	0.1676	234.08	
5 A	12.70	122.5	1.40	0.40	175.28	57.83	0.2026	283.49	
5 B	0.95	39.0	0.38	0.20	55.48	34.34	0.0224	26.65	Defective; large cavity.
5 C	11.98	106.5	1.40	0.65	175.28	87.20	0.1564	265.70	
5 D	5.10	68.0	0.95	0.49	122.43	57.83	0.0666	117.40	Defective; several blowholes.
6 A	6.36	69.5	1.15	0.50	145.92	69.58	0.0694	143.51	Defective through liquation.
6 B	11.45	100.0	1.46	0.60	182.32	81.32	0.1391	253.61	
6 C	7.95	87.0	1.14	0.45	144.74	63.69	0.1068	179.41	Defective through liquation.
6 D	5.82	61.0	1.05	0.55	134.17	75.45	0.0539	130.83	Defective through liquation.
7 A	1.45	14.0	1.38	1.25	172.93	157.66	0.0029	32.37	
7 B	0.30	5.0	1.78	0.78	102.46	102.46	0.0004	7.10	Defective; large cavity.
7 C	1.89	21.8	1.65	0.70	204.64	93.07	0.0065	42.85	
7 D	1.42	13.0	1.55	0.80	192.89	104.81	0.0025	31.56	
8 A	0.07	3.0	0.90	0.90	116.55	116.55	0.0013	2.00	
8 B	0.22	4.0	1.02	1.02	130.65	130.65	0.0034	5.27	
8 C	0.16	3.0	1.05	1.05	134.17	134.17	0.0013	3.85	
8 D	0.15	3.5	0.82	0.82	107.16	107.16	0.0019	3.74	
									Diameter. — Equivalent maximum torsional moment of piece ¼ inch diameter.
									Inches.
9 D	0.08	1.5	1.50	1.50	64.90	64.90	0.0008	0.63	0.970 — 17.58
11 A	0.12	0.75	3.40	3.40	58.51	58.51	0.0002	0.36	0.955 — 16.44
12 A	0.08	1.0	1.20	1.20	21.10	21.10	0.0003	0.25	0.900 — 7.06
13 C	0.10	1.0	1.45	1.45	32.41	32.41	0.0003	0.41	0.960 — 8.94
14 D	0.06	1.0	2.80	2.80	48.31	48.31	0.0003	0.19	0.955 — 13.54
15 B	0.09	1.0	3.70	3.70	63.62	63.62	0.0003	0.28	0.965 — 17.28
15 D	0.09	1.0	2.45	2.45	42.35	42.35	0.0003	0.28	0.940 — 12.45
16 A	0.07	1.0	1.30	1.30	56.47	56.47	0.0003	0.54	0.945 — 16.34
16 B	0.09	0.5	2.15	2.15	102.30	102.30	0.0001	0.68	0.945 — 29.60
16 C	0.12	1.25	4.00	4.00	68.72	68.72	0.0004	0.37	0.890 — 23.80
17 A	0.05	2.0	1.45	1.45	62.79	62.79	0.0013	0.43	0.940 — 18.46
17 C	0.12	1.2	2.20	2.20	94.41	94.41	0.0004	0.92	0.922 — 29.41
17 D	0.10	1.75	1.65	1.65	36.45	36.45	0.0004	0.45	0.625 — 36.45
18 A	0.05	1.0	1.05	1.05	45.93	45.93	0.0003	0.40	0.895 — 15.64
18 C	0.10	2.5	1.20	1.20	27.37	27.37	0.0009	0.49	
18 D	0.08	1.6	1.20	1.20	27.37	27.37	0.0004	0.37	

TESTS BY TORSIONAL STRESS—Continued.

	Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic limit.	Ductility, extension of exterior fiber.	Resilience.	Remarks.
	Sq. in.	*Deg.*	*Ins.*	*Ins.*	*Ft. lbs.*	*Ft. lbs.*		*Ft. lbs.*	
	0.02	1.1	0.33	0.33	9.83	9.83	0.00002	0.13	
	0.14	2.75	1.28	1.28	29.00	29.00	0.00010	0.64	
	0.02	1.75	0.38	0.38	10.84	10.84	0.00004	0.17	
	0.01	0.5	0.38	0.38	10.84	10.84	0.00001	0.63	Large crystalline, weakest; fine granular, strongest.
	0.30	4.5	1.60	1.60	35.44	35.44	0.00030	1.30	Blowhole in center.
	0.20	2.6	1.10	1.10	25.35	25.35	0.00009	0.85	
	0.04	1.75	0.45	0.45	12.24	12.24	0.00004	0.24	
	0.57	4.5	1.90	1.86	41.50	40.63	0.00030	2.25	
	0.43	5.5	1.15	1.15	26.36	26.36	0.0005	1.82	
	1.26	1.0	1.50	1.20	34.45	27.37	0.0015	4.99	
	0.20	4.0	0.82	0.80	19.70	19.30	0.0002	0.92	
	0.10	3.25	0.45	0.45	12.24	12.24	0.00015	0.53	
	2.78	26.5	1.15	0.83	26.36	19.91	0.0103	11.24	
	1.64	22.0	0.85	0.60	20.31	15.26	0.0072	6.98	
	2.13	26.0	0.92	0.65	21.72	16.31	0.0100	8.93	
A	1.28	16.5	0.90	0.63	21.32	15.90	0.0040	5.41	
B	8.13	79.5	1.98	0.60	24.95	15.30	0.0899	32.99	
C	9.88	109.0	1.10	0.55	25.35	14.26	0.1634	40.77	
D	3.50	42.0	0.90	0.60	21.32	15.26	0.0259	14.63	
A	11.38	153.0	0.90	0.50	21.32	13.25	0.3024	48.47	
B	10.95	102.5	1.30	0.70	29.39	17.28	0.1456	44.18	
C	9.30	123.5	0.85	0.45	20.31	12.24	0.2057	39.53	
D	9.96	148.0	0.88	0.60	20.91	15.26	0.2851	43.20	
A	7.45	117.0	0.70	0.40	17.28	11.23	0.1863	32.66	Blowhole in center; defective.
B	18.05	251.0	0.80	0.45	19.30	12.24	0.6953	77.34	
C	13.18	213.0	0.70	0.33	17.28	9.84	0.5328	58.10	Blowhole in center; defective.
D	18.40	190.0	1.15	0.40	26.36	11.23	0.4401	75.22	
A	14.38	277.0	0.68	0.18	16.78	6.31	0.8118	65.85	Blowhole in center; defective.
B	20.75	362.5	0.70	0.30	17.28	9.21	1.2156	92.98	
C	18.50	412.5	0.80	0.22	19.30	7.19	1.4620	87.81	
D	15.86	334.5	0.55	0.22	14.26	7.19	1.0804	74.22	Blowhole in center; defective.
A	1.14	259.0	0.10	0.00	5.17	0.00	0.7308	72.39	(Defective test.) Diagram incorrect. Tested with 100 pounds upon arm.
B	34.25	610.0	0.68	0.15	16.78	6.30	2.4741	154.11	
C	26.30	504.0	0.70	0.20	17.38	7.19	1.9260	120.30	
D	21.73	402.0	0.60	0.20	15.26	7.19	1.8637	103.55	
A	25.10	591.0	0.55	0.15	14.26	6.18	2.3750	120.86	
B	51.16	516.0	0.55	0.12	14.26	5.58	1.9863	102.86	
C	21.95	524.0	0.50	0.15	13.25	6.18	2.0278	106.08	
D	16.82	596.0	0.30	0.10	9.21	5.17	2.4010	91.99	
A	10.72	105.0	1.22	0.50	127.49	54.41	0.1524	195.89	
B	18.23	158.0	1.40	0.40	145.13	44.32	0.3201	331.69	
C	21.27	177.0	1.40	0.50	145.13	54.41	0.3900	386.49	
D	20.20	172.0	1.50	0.45	155.21	49.36	0.3712	367.32	

NOTE.—In making up the averages of results given in the table on pages 330,378, the pieces marked ective in the above table are rejected.

ars No. 1 to No. 8 inclusive, and No. 30, were tested with 100-pound weight on arm of torsion ma-ne. Nos. 9 D, 16 A, 16 B, 17 A, 17 C, and 18 A were tested with 30-pound weight, and the remainder thout any weight on arm.

The pieces were all 0.625 inch diameter except Nos. 9 D to 18 A, inclusive. The diameters of these given in the column headed "Remarks." The torsional moment of the piece is given in the table, d in the column of "Remarks" is given the equivalent torsional moment of a piece of standard size, ich is found by dividing the moment as found from the diagram by the ratio of the cube of the di-eter of the piece to the cube of 0.625 inch, the torsional strength varying as the cube of the diameter. e resilience of the pieces is the resilience of the piece as tested, and not that of a specimen of stand-l size. The latter cannot be given, as at present the relation of the torsional resilience to diameter unknown.

RECORD OF TESTS BY TRANSVERSE STRESS.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY

TABLE CXXXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 31.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Dimensions: L between supports, $l = 22''$. Breadth, $b = 0.956''$. Depth, $d = 0.977''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0110	.....	.....
20	0.0145	.....	.....
40	0.0207	.....	5,769,739
80	0.0321	.....	7,441,347
120	0.0433	.....	8,274,843
160	0.0552	.....	8,654,608
200	0.0674	.....	8,860,059
3	.....	0.0109	.....
240	0.0822	.....	8,717,780
280	0.0982	.....	8,513,596
320	0.1188	.....	8,042,667
360	0.1568	.....	6,855,244

Resistance decreases slowly.

On putting on 380 pounds, a crack was fo the under side of bar. The resistance dec as the deflection was increased, till the bar

Breaking load, 360 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 13,01$

The fracture was full of blowholes, an partly oxidized, showing that the crack old one.

(Bar defective, test worthless.)

TABLE CXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 32.—Material: Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—Dimensions: between supports. $l = 22''$. Breadth, $b = 0.956''$. Depth, $d = 0.982''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4 \Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0060	.....	.....
20	0.0104	.....	.....
40	0.0185	.....	6,357,759
80	0.0278	.....	8,461,765
120	0.0376	.....	9,384,459
160	0.0472	.....	9,967,673
200	0.0572	.....	10,281,341
3	.....	0.0035	.....
240	0.0668	.....	10,564,538
280	0.0769	.....	10,706,500
320	0.0880	.....	10,692,594
360	0.0983	.....	10,768,738
400	0.1105	.....	10,644,211
3	.....	0.0145	.....
440	0.1232	Beam sinks.	10,501,656
480	0.1389	.....	10,161,429
520	0.1535	.....	9,961,177
560	0.1719	.....	9,579,171
600	0.1963	.....	8,987,663
3	.....	0.0577	.....
600	0.2065	.....	.....

Resistance decreased in 2m to 586 pounds.
Resistance decreased in 1h 48m to 562 pounds.

Load.	Deflection. Δ	Set.	Modulu elastici $E = \frac{P}{4\Delta}$
Pounds.	*Inches.*	*Inches.*	
3	.....	0.0655	.....
600	0.2095	.....	.....
640	0.2365	.....	7,957
680	0.2867	.....	.....
720	0.3511	.....	6,030
760	0.4609	.....	.....
800	0.6031	.....	3,900
3	.....	0.4113	.....
800	0.6202	.....	.....
840	0.7792	.....	.....
880	1.0427	.....	.....
920	1.3217	.....	.....
960	1.74	.....	.....
1,000	2.13	.....	1,38
1,040	2.63	.....	.....
1,080	3.78	.....	840
3	.....	3.40	.....

Bar bent to a deflection of 8″ without br
Breaking load (or the load causing defle
3½″) 1,080 pounds.

Modulus of rupture, $R = \frac{3Pl}{2bd^2} = 38,659.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXL.—ALLOY OF COPPER AND TIN.

l mark: No. 33.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.973″. Depth, 0.977″.

Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0042			1,000	0.3245		
0.0075			3		0.0910	
0.0125		9,387,752	1,040	0.3611		
0.0236		9,969,873	1,080	0.3959		8,002,946
0.0332		10,603,633	1,120	0.4493		
0.0409		11,478,087	1,160	0.5122		
0.0508		11,549,891	1,200	0.5727		6,147,034
	0.0049		3		0.2827	
0.0606		11,618,503	1,200	0.5892		
0.0701		11,717,949	1,240	0.6475		
0.0793		11,838,275	1,280	0.7485		
0.0890		11,869,273	1,300	0.8111		
0.0980		11,974,171	1,320	0.8701		
	0.0036(?)		1,360	0.9892		
0.1071		12,052,435	1,400	1.1419		3,596,760
0.1168			1,440	1.3032		
0.1255		12,155,454	1,480	1.4878		
0.1355		12,127,844	1,520	1.6700		
0.1461		12,047,936	1,560	1.8500		
	0.0112		1,600	2.1000		2,235,179
0.1568			1,640	2.4500		
0.1678		11,888,540	1,680	3.1000		
0.1800	Beam sinks slowly.		1,700	3.5000		1,424,927
0.1933			3		2.81	
0.2074		11,315,997	1,700			
	0.0284		Bar broke after a deflection of about 4″.			
0.2269			Breaking load 1,700 pounds.			
0.2475						
0.2716		9,937,327	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=60{,}403$ pounds.			
0.2964						

TABLE CXLI.—ALLOY OF COPPER AND TIN.

mark: No. 34.—Material: Alloy.—Original mixture: 82.5 Cu, 17.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.950″. Depth, 0.970″.

0.0060			1,000	0.2060		14,903,838
0.0080			10		0.0098	
0.0135		9,096,944	1,040	0.2157		14,802,137
0.0227		10,820,152	1,080	0.2264		
0.0316		11,659,056	1,120	0.2377		14,466,320
0.0405		12,129,260	1,160	0.2472		
0.0481		12,765,982	1,200	0.2614		
	0.0035		1,240	0.2728		
0.0560		13,158,079	1,280	0.2852		
0.0646		13,307,417	1,320	0.3003		13,495,466
0.0729		13,476,957	1,360	0.3175		
0.0804		13,747,250	1,400	0.3330		
0.0881		13,939,699	10		0.0436	
	0.0035		1,440	0.3495		
0.0940		14,371,235	1,480	0.3693		
0.1027		14,349,611	1,520	0.3880		12,055,389
0.1099		14,526,967	1,560	0.4170		
0.1174		14,644,993	1,600	0.4393		
0.1265		14,562,305	10		0.0935	
	0.0028		1,640	0.4575		
0.1340		14,663,731	1,680	0.4825		
0.1409		14,817,235	1,720	0.5247		10,064,370
0.1473		15,007,180	1,760	0.5464		
0.1549		15,063,694	1,800	0.5757		
0.1631		15,059,318	1,840	0.6125		9,224,187
	0.0051		Broke suddenly with a ringing sound about 30 seconds after putting on the strain, and just after reading the deflection.			
0.1618						
nce decreased in 19h 45m to 788 pounds.			Breaking load, 1,840 pounds.			
	0.0047					
0.1702		15,152,664	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=67{,}930$.			
0.1790		15,093,815				
0.1873		15,080,625				
0.1959		15,045,481				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.965″. Depth, 0.969″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4\Delta bd^3}$	Load.	Deflection.	Set.	Modulus of elasticity. $E = \frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0. 0032	.....	.....	480	0. 0994	.....	14, 626, 266
20	0. 0055	.....	.....	520	0. 1059	.....	14, 967, 942
40	0. 0095	.....	12, 805, 342	560	0. 1145	.....	14, 874, 225
80	0. 0180	.....	13, 516, 751	600	0. 1249	.....	14, 847, 329
120	0. 0276	.....	13, 222, 905	3	.....	0. 0038	.....
160	0. 0358	.....	13, 592, 263	640	0. 1308	.....	14, 880, 829
200	0. 0436	.....	13, 950, 775	680	0. 1385	.....	14, 931, 859
3	.....	0. 0035	.....	720	0. 1458	.....	15, 018, 612
240	0. 0519	.....	14, 063, 667	760	0. 1528	.....	15, 136, 728
280	0. 0601	.....	14, 168, 971	800	0. 1606	.....	15, 149, 535
320	0. 0689	.....	14, 092, 421	3	.....	0. 0045	.....
360	0. 0766	.....	14, 293, 167	840	Broke in putting on strain.		
400	0. 0852	.....	14, 278, 257	Breaking load, 820 pounds.			
3	.....	0. 0035	.....	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 29,926$.			
440	0. 0932	.....	14, 357, 944				

TABLE CXLIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 36.—Material: Alloy (second casting).—Original mixture: 72.5 Cu, 27.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.998″. Depth, 1.004″.

10	0. 0013	.....	.....	240	0. 0386	.....	16, 387, 041
20	0. 0036	.....	.....	260	0. 0422	.....	16, 238, 179
40	0. 0077	.....	13, 691, 334	280	0. 0453	.....	16, 290, 571
80	0. 0143	.....	14, 744, 515	290	0. 0475	.....	16, 090, 922
120	0. 0208	.....	15, 205, 280	300	Broke in applying strain.		
160	0. 0276	.....	15, 278, 736				
200	0. 0329	.....	16, 021, 775	Breaking load, 290 pounds.			
4	.....	0. 0013	.....	Modulus of rupture, $R = \frac{3}{2}\frac{P\,l}{bd^2} = 9,512$.			
200	0. 0330	.....	.....				
220	0. 0358	.....	16, 196, 313				

TABLE CXLIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 37.—Material: Alloy.—Original mixture: 67.5 Cu, 32.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.965″. Depth, 0.987″.

10	0. 0068	.....	.....	200	0. 0403	.....	14, 238, 174
20	0. 0097	.....	.....	5	.....	0. 0032	.....
30	0. 0116	.....	.....	220	0. 0435	.....	14, 509, 843
40	0. 0133	.....	8, 628, 548	240	0. 0466	.....	14, 775, 922
60	0. 0161	.....	10, 691, 894	260	0. 0501	.....	14, 888, 979
80	0. 0199	.....	11, 533, 636	270	0. 0520	.....	14, 896, 691
100	0. 0239	.....	12, 473, 879	280	Broke in applying strain.		
120	0. 0280	.....	12, 295, 678				
140	0. 0313	.....	12, 832, 669	Breaking load, 270 pounds.			
160	0. 0341	.....	13, 461, 545	Modulus of rupture, $R = \frac{3}{2}\frac{P\,l}{bd^2} = 9.477$.			
180	0. 0375	.....	13, 771, 159				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLV.—ALLOY OF COPPER AND TIN.

l mark: No. 38 (E—F).—Material: Alloy.—Original mixture: 62.5 Cu, 37.5 Sn.—Dimensions: gth between supports, 9″. Breadth, 0.985″. Depth, 0.995″. Middle portion of original bar.

Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Inches.	*Inches.*	
0.0035		
0.0065		1,213,662
0.0125		
0.0135		1,391,324
0.0145		
0.0155		1,696,517
	0.0035	
0.0155		
0.0165		1,623,297
0.0173		1,954,287
0.0185		2,030,581
Broke in applying strain.		

Breaking load 210 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=2,997$.

The irregularity of the first three deflections given above was caused by the bar not resting evenly on the supports. It was slightly warped and at the beginning of the test only the corners touched the supports. The corners appeared to be crushed at the lower pressures below 80 pounds.

TABLE CXLVI.—ALLOY OF COPPER AND TIN.

l mark: No. 39 (B—E).—Material: Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Dimensions: gth between supports, 17″. Breadth, 1″. Depth, 0.985″. Lower portion of original bar.

Deflection	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Inches.	*Inches.*	
0.0042		
0.0085		6,350,411
0.0105		7,588,929
0.0132		7,983,956
0.0150		8,739,548
0.0180		8,710,948
0.0210		8,690,546

Broke about 20 seconds after applying strain.

Breaking load, 142 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=3,732$.

TABLE CXLVII.—ALLOY OF COPPER AND TIN.

mark: No. 40 (A—E).—Material: Alloy.—Original mixture: 52.5 Cu, 47.5 Sn.—Dimensions: gth between supports, 9″. Breadth, 1.015″. Depth, 1″. Upper portion of original bar.

Deflection Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Inches.	*Inches.*	
0.0020		
0.0037		1,989,682
0.0050		2,190,591
0.0055		2,644,380
0.0065		2,790,034
0.0071		3,060,051
0.0080		3,164,686
Broke in applying strain.		

Breaking load, 150 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=1,995$.

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXLVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (A—F).—Material: Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Dimensi
Length between supports, 15″. Breadth, 0.962″. Depth, 0.980″. Upper portion of original bar

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\,\Delta\,bd^3}$	Load.	Deflection. Δ	Set.	Modulus elasticity. $E=\frac{Pl^3}{4\,\Delta\,bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0018	.....	.....	180	0.0167	.....	10,044,22
20	0.0030	.....	.....	200	0.0180	.....	10,354,29
40	0.0047	.....	7,930,902	4	.....	0.0022	.....
60	0.0036	.....	8,875,059	220	0.0186	.....	11,022,29
80	0.0075	.....	9,940,064	240	Broke in applying strain.		
100	0.0098	.....	9,508,991				
120	0.0115	.....	9,723,976	Breaking load, 230 pounds.			
140	0.0134	.....	9,736,077	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=5,601.$			
160	0.0151	.....	9,874,239				

TABLE CXLIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (A—F).—Material: Alloy.—Original mixture: 42.5 Cu, 57.5 Sn.—Dimens
Length between supports, 18″. Breadth, 0.995″. Depth, 0.995″.

22	0.0033	.....	.....	202	0.0319	.....	9,419,45
42	0.0060	.....	10,412,693	222	0.0357	.....	9,250,17
82	0.0124	.....	9,836,878	227	Broke in applying strain 5 inches fr		
102	0.0158	.....	9,603,028		end.		
122	0.0188	.....	9,653,107	Breaking load, 222 pounds.			
142	0.0215	.....	9,824,600	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6,084.$			
162	0.0249	.....	9,677,893				
182	0.0285	.....	9,499,300				

TABLE CL.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (F—C).—Material: Alloy.—Piece remaining after previous test, 13 i
long.—Dimensions: Length between supports, 12″.

22	0.0022	.....	.....	322	0.0282	.....	5,032,6
42	0.0043	.....	4,304,986	362	0.0310	.....	4,862,4
82	0.0091	.....	3,971,584				
122	0.0132	.....	4,073,589	Broke just as strain was applied.			
162	0.0164	.....	4,353,740	Breaking load, 362 pounds.			
202	0.0202	.....	4,407,490	Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6,605.$			
242	0.0220	.....	4,848,239				
282	0.0264	.....	4,708,000				

TABLE CLI.—ALLOY OF COPPER AND TIN.

Original mark: No. 43.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Dimensions: L
between supports, 22″. Breadth, 0.970″. Depth, 0.990″.

10	0.0038	.....	.....	160	0.0577	.....	7,842,8
20	0.0050	.....	11,313,336	180	0.0676	.....	7,531,0
40	0.0106	.....	10,672,961	200	0.0799	.....	7,079,6
60	0.0169	.....	10,041,426	6	.....	0.0202	.....
80	0.0228	.....	9,923,982	200	Broke just as beam rose.		
100	0.0308	.....	9,184,904	Breaking load, 200 pounds.			
	Beam sinks slowly.			Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=6,942.$			
120	0.0389	.....	8,724,939				
140	0.0482	.....	8,215,079				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLII.—ALLOY OF COPPER AND TIN.

Original mark: No. 44.—Material: Alloy.—Original mixture: 32.5 Cu, 67.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.985″. Depth, 0.990″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $E=\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0019		
20	0.0075		7,427,369
40	0.0176		6,330,144
60	0.0247		6,765,822
80	0.0319		6,984,987
100	0.0406		6,860,256
	Beam sinks slowly.		
120	0.0505		6,618,447
140	0.0607		6,424,002
160	0.0743		5,997,876
180	0.0907		5,527,535
200	0.1098		5,073,241
6		0.0325	
200	0.1122		
	Heard several slight cracks.		
210	Bar broke just as beam rose.		

Breaking load, 210 pounds.

Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=7,178.$

TABLE CLIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 45.—Material: Alloy.—Original mixture: 27.5 Cu, 72.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.978″. Depth, 0.985″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\Delta bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0026		
20	0.0061		9,338,147
40	0.0146		7,803,107
80	0.0325		7,010,792
	Beam sinks slowly.		
100	0.0403		7,067,332
120	0.0487		7,017,989
140	0.0583		6,839,430
160	0.0696		6,547,436
5		0.0145	
160	0.0720		
Distance to strain decreased in 1 min. to 154 pounds.			
Distance to strain decreased in 3 min. to 150 pounds.			
Distance to strain decreased in 44 hours to 104 pounds.			
Distance to strain decrea ed in 69 hours to 100 pounds.			
4		0.0400	
100	0.0763		
120	0.0817		
140	0.0887		
160	0.0970		
180	0.1053		4,868,606
200	0.1162		4,902,125
220	0.1297		4,831,069
240	0.1480		
260	0.1647		4,496,144
280	0.1846		
300	0.2057		4,153,819
4		0.0873	
300	0.2073		
310	0.2204		4,005,997
320	Broke just as beam rose.		

Breaking load, 320 pounds.

Modulus of rupture, $R=\frac{2}{3}\frac{Pl}{bd^2}=11,128.$

TABLE CLIV.—ALLOY OF COPPER AND TIN.

Original mark: No. 46.—Material: Alloy.—Original mixture: 22.5 Cu, 77.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.980″. Depth, 0.992″.

10	0.0036		
20	0.0066		8,432,047
40	0.0141		7,893,831
60	0.0197		8,474,849
80	0.0272		8,182,160
100	0.0363		7,665,497
	Beam sinks slowly.		
4		0.0047	
20	0.0460		7,258,892
40	0.0579		6,728,160
60	0.0709		6,279,437
80	0.0868		5,770,317
100	0.1045		5,325,503
4		0.0357	
20	0.1239		
40	0.1487		4,491,042
260	0.1675		
280	0.1923		4,051,591
300	0.2203		
4		0.1044	
320	0.2479		3,591,869
340	0.2814		
360	0.3163		3,167,015
380	0.3523		
400	0.3908		2,848,081
10		0.2051	
400	0.4051		
420	Broke in applying strain.		

Breaking load 400 pounds.

Modulus of rupture, $R=\frac{2}{3}\frac{Pl}{bd^2}=13,687.$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLO

TABLE CLV.—ALLOY OF COPPER AND TIN.

Original mark: No. 47.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: I between supports, 22″. Breadth, 0.996″. Depth, 0.983″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$
Pounds.	*Inches.*	*Inches.*	
10	0.0027		
20	0.0070		8,039,339
40	0.0153		7,356,258
60	0.0256		6,594,770
80	0.0365		6,167,163
	Beam sinks slowly.		
100	0.0499		5,638,814
5		0.0092	
120	0.0617		5,472,481
140	0.0804		4,899,597
160	0.1042		4,320,565
180	0.1343		3,771,245
200	0.1666		3,377,873
5		0.0821	
200	0.1798		
220	0.2145		
240	0.2563		2,697,980
260	0.3021		
270	0.3367		
280	0.3762		832,406
290	0.4147		
300	0.4597		
5		0.3084	

The beam was observed to rise, and another reading of set was taken in 2 minutes.

5		0.3022	

The beam rose again, pushed forward the poise till beam balanced at 10 pounds.
Time 2 minutes.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$

In 2 minutes more, beam balanced at 14 p
The pressure screw was then run back til
balanced again at 5 pounds, and another r
of set taken.

Pounds.	*Inches.*	*Inches.*	
5		0.2998	

Beam rose again.
In 2 minutes balanced at 10 pounds.
In 10 minutes balanced at 16 pounds.
In 39 minutes balanced at 23 pounds.
Ran back pressure-screw till beam ba
again at 5 pounds.

5		0.2902	

In 4 minutes beam rose again.
In 23 minutes beam balanced at 14 pound
In 1 hour and 36 minutes beam balance
pounds.
Ran back pressure-screw till beam ba
again at 5 pounds.

5		0.2845	

Total *decrease of set* in 2 hours and 29 m
0.3084—0.2845 = 0.0239 inches.
Replaced load of 280 pounds.

280	0.4849		
300	0.5332		
310	Broke on applying strain.		

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 10,288.$

TABLE CLVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 48.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: between supports, 22″. Breadth, 0.985″. Depth, 0.990″.

10	0.0025		
20	0.0050		
40	0.0141		7,901,458
60	0.0230		7,249,195
80	0.0352		6,330,144
	Beam sinks slowly.		
100	0.0508		5,482,803
5		0.0120	
120	0.0760		4,397,784
140	0.0969		4,024,116
160	0.1262		3,531,237
180	0.1592		
200	0.2044		2,725,307
5		0.1238	
200	0.2268		
220	0.2916		
240	0.4078		1,639,194
260	0.5210		
270	0.5763		
280	0.6458		1,207,609
290	0.7185		
300	0.8025		1,041,220
5		0.6742	

Scale beam rose.
In 2 minutes balanced at 20 pounds.
In 4 minutes balanced at 29 pounds.
In 15 minutes balanced at 34 pounds.
Ran back pressure-screw till beam
again at 5 pounds.

5		0.6555	

Beam rose again, balanced at 12 pou
minutes.

5		0.6508	

Total decrease of set in 20 minutes,
0.6508 = 0.0234 inches.
Beam rose again, but test was continu
out further waiting.

260	0.8304		
280	0.9018		
300	1.0760	Beam sank rapidly.	
300	Repeated.	Bar broke just as be	

Breaking load, 300 pounds.

Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 10,2$

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

[*Second series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLVII.—ALLOY OF COPPER AND TIN.

l mark: No. 49.—Material: Alloy.—Original mixture: 7.5 Cu. 92.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.990″. Depth, 0.995″.

Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\,\Delta\,bd^3}$
Inches.	*Inches.*		*Pounds.*	*Inches*	*Inches.*	
0.0009			3		0.2872	
0.0037			220	0.5232		
0.0137		7,969,719	240	0.8017		817,152
0.0233		7,020,689	250	0.10072		
0.0367		5,963,860	260	1.3300		
Beam sinks.			270	1.7810		
0.0537		5,083,424	280	2.6700		286,233
	0.0128		290	3.6700		215,693
0.0751		4,361,591	Bar bent without breaking.			
0.1153			Breaking load (or load causing deflection of 3½ inches), 290 pounds.			
0.1587		2,751,989				
0.2382			Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 9,764.$			
0.3582		1,524,081				

TABLE CLVIII.—ALLOY OF COPPER AND TIN.

l mark: No. 50.—Material: Alloy.—Original mixture: 2.5 Cu. 97.5 Sn.—Dimensions: Length between supports, 22″. Breadth, 0.991″. Depth, 0.997″.

0.0032		8,470,302	210	0.8512		
0.0081		6,692,585	Repeated—			
0.0221		4,905,876	210	1.0322		
0.0331		4,913,288	210	1.0800		
Beam sinks slowly.			220	1.3800		432,108
0.0472		4,594,063	230	1.6800		
0.0629		4,309,216	240	2.4300		
	0.0164		250	3.9300		172,423
0.0909		3,578,213				
0.1418		2,676,090	Bar bent without breaking.			
0.2217		1,956,154	Breaking load (or load causing 3½ inches deflection), 250 pounds.			
0.3777						
0.5797		935,138	Modulus of rupture, $R = \frac{3}{2}\frac{Pl}{bd^2} = 8,375.$			
	0.5042					
0.6912						

RECORD OF TESTS BY TENSILE STRESS.

[*Second series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLIX.—ALLOY OF COPPER AND TIN.

l mark: No. 31 A.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

per are	Elongation in 5 inches.	Set.	Elongation in parts of original length.
ds.	*Inches.*	*Inches.*	
000	0.0010		.0002
000	0.0042		.0008
000	0.0079		.0016
000	0.0123		.0025
000		0.0030	
000	0.0172		.0034
000	0.0230		.0046
000	0.0306		.0061
000	0.0373		.0075
000		0.0230	
000	0.0455		.0091
000	0.0530		.0106
000	0.0617		.0123
000	0.0699		.0139
200		0.0620	
000	0.0849		.0170

Broke just as reading was taken ¼ inch from C. end.

Diameter of fractured section, 0.770 inch.

Fracture full of small blowholes.

Tenacity per square inch, original section, 13,000 pounds.

Tenacity per square inch, fractured section, 13,958 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNO

TABLE CLX.—ALLOY OF COPPER AND TIN.

Original mark: No. 31 B.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0010	.....	.0002
2,000	0.0025	.....	.0005
4,000	0.0055	.....	.0011
200	.....	0.0005	.....
5,000	0.0077	.....	.0015
6,000	0.0103	.....	.0021
7,000	0.0131	.....	.0026
8,000	0.0168	.....	.0034
200	.....	0.0081	.....
10,000	0.0247	.....	.0049
12,000	0.0348	.....	.0070
200	.....	0.0273	.....
14,000	0.0531	.....	.0106
15,000	0.0666	.....	.0133
15,250	0.0773	.....	.0155

Broke 2 inches from D end after taking
Diameter of fractured section, 0.770 of blowholes.
Tenacity per square inch, original secti pounds.
Tenacity per square inch, fractured 16,374 pounds.
The bar was defective in consequenc ration of metals, and blowholes throu whole length.

TABLE CLXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 32 A.—Material: Alloy.—Original mixture, 92.5 Cu, 7.5 Sn.—Dimension: 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
800	0.0010	.....	.0002
2,000	0.0027	.....	.0005
3,000	0.0039	.....	.0008
4,000	0.0051	.....	.0010
200	.....	0.0011	.....
6,000	0.0073	.....	.0015
8,000	0.0091	.....	.0018
200	.....	0.0044	.....
10,000	0.0104	.....	.0021
12,000	0.0120	.....	.0024
200	.....	0.0079	.....
14,000	0.0146	.....	.0029
16,000	0.0222	.....	.0044
200	.....	0.0181	.....
18,000	0.0506	.....	.0101
In 1 min.	0.0546	.....	.0109
19,000	0.0664	.....	.0133
20,000	0.0956	.....	.0191

Load per square inch.	Elongation in 5 inches.	Set.	Elon par ina
Pounds	*Inches.*	*Inches.*	
200	.....	0.0906	....
22,000	0.1509	.....	
23,000	0.1793	.....	
In 1 min.	0.1916	.....	
24,000	0.2156	.....	
In 20 sec.	0.2218	.....	
200	.....	0.2110	....
26,000	0.3038	.....	
28,000	0.3896	.....	
28,500	Broke 1 inch from C end.		

Fractured section elliptical, diameter 0.732 inch.
Tenacity per square inch, original se pounds.
Tenacity per square inch, fracture 35,922 pounds.
Several very small blowholes in fra face.

TABLE CLXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 32 B.—Material: Alloy.—Original mixture: 92 5 Cu, 7.5 Sn.—Dimensio 5″. Diameter, 0.798″.

800	0.0004	.....	.0001
2,000	0.0038	.....	.0008
3,000	0.0062	.....	.0012
4,000	0.0085	.....	.0017
6,000	0.0138	.....	.0028
8,000	0.0203	.....	.0041
200	.....	0.0039	.....
10,000	0.0272	.....	.0054
12,000	0.0363	.....	.0072
200	.....	0.0199	.....
14,000	0.0459	.....	.0092
16,000	0.0554	.....	.0111
200	.....	0.0449	.....
18,000	0.0707	.....	.0141
20,000	0.1044	.....	.0208

200	.....	0.0944	...
22,000	0.1516	.....	
24,000	0.2135	.....	
25,000	0.2499	.....	
In 1 min.	0.2594	.....	
26,000	0.2980	.....	
27,000	0.3338	.....	
27,300	0.3532	.....	

Broke ¾ inch from D end.
Fractured section elliptical, diame 0.720 inch.
Tenacity per square inch, original se pounds.
Tenacity per square inch, fractu 32,844 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

ICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXIII.—ALLOY OF COPPER AND TIN.

rk: No. 33 A.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Dimensions: Length 5″. Diameter, 0.798″.

Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0022	.....	.0004	20,000	0.0465	.....	.0081
0.0044	.....	.0009	200	.....	0.0261	.....
0.0072	.....	.0014	22,000	0.0485	.....	.0097
0.0093	.....	.0019	24,000	0.0605	.....	.0121
.....	0.0005	.....	200	.....	0.0467	.....
0.0128	.....	.0026	26,000	0.0804	.....	.0161
0.0185	.....	.0037	27,000	0.0927	.....	.0185
.....	0.0008	.....	28,000	0.1129	.....	.0226
(?) 0.0184	.....	.0037	200	.....	0.0955	.....
0.0218	.....	.0044	29,000	Broke in middle just as beam rose.		
.....	0.0037	.....	Diameter of fractured section, 0.776 inch.			
0.0246	.....	.0049	Tenacity per square inch, original section, 29,000 pounds.			
0.0292	.....	.0058				
.....	0.0114	.....	Tenacity per square inch, fractured section, 30 658 pounds.			
0.0342	.....	.0068				

TABLE CLXIV.—ALLOY OF COPPER AND TIN.

rk: No. 33 B.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

0.0025	.....	.0005	24,000	0.0905	.....	.0191
0.0052	.....	.0010	200	.....	0.0665	.....
0.0097	.....	.0019	26,000	0.1040	.....	.0208
0.0139	.....	.0028	28,000	0.1271	.....	.0254
0.0206	.....	.0041	200	.....	0.1063	.....
0.0275	.....	.0055	30,000	0.1561	.....	.0312
.....	−0.0008(?)	.....	32,000	0.2007	.....	.0401
0.0330	.....	.0066	200	.....	0.1811	.....
0.0396	.....	.0079	33,000	0.2270	.....	.0454
.....	0.0049	.....	33,200	0.2432	.....	.0485
0.0473	.....	.0094				
0.0541	.....	.0108	Broke in middle.			
.....	0.0200	.....	Diameter of fractured section, 0.770 inch.			
0.0623	.....	.0125	Tenacity per square inch, original section, 33,200 pounds.			
0.0709	.....	.0142				
.....	0.0421	.....	Tenacity per square inch, fractured section, 35,648 pounds.			
0.0793	.....	.0159				

TABLE CLXV.—ALLOY OF COPPER AND TIN.

rk: No. 34 A.—Material: Alloy.—Original mixture: 82.5 Cu, 17.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

0.0032	.....	.0006	26,000	0.0224	.....	.0045
0.0074	.....	.0015	28,000	0.0244	.....	.0049
0.0104	.....	.0021	200	.....	0.0042	.....
0.0125	.....	.0025	30,000	0.0264	.....	.0053
.....	−0.0004(?)	.....	32,000	0.0288	.....	.0058
0.0137	.....	.0027	200	.....	0.0091	.....
0.0150	.....	.0030	34,000	0.0316	.....	.0063
.....	0.0001	.....	37,300	0.0357	.....	.0071
0.0161	.....	.0032	40,200	Broke ⅜ inch from A end.		
0.0170	.....	.0034	Diameter of fractured section, 0.795 inch.			
0.0176	.....	.0035	Tenacity per square inch of original section, 40,200 pounds.			
0.0194	.....	.0039				
0.0200	.....	.0040	Tenacity per square inch of fractured section, 40,492 pounds.			
0.0216	.....	.0043				
.....	0.0002	.....				

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY

TABLE CLXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 34 B.—Material: Alloy.—Original mixture, 82.5 Cu, 17.5 Sn.—Dimensions: Le 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongati parts o inal le
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
2,000	0.0019	.....	.0004	22,000	0.0216	.....	.00
3,000	0.0034	.....	.0007	24,000	0.0244	.....	.00
4,000	0.0054	.....	.0011	2 0	.....	+0.0021	.....
6,000	0.0080	.....	.0016	26,000	0.0269	.....	.0(
8,000	0.0110	.....	.0022	28,000	0.0296	.....	.0(
10,000	0.0119	.....	.0024	30,000	0.0324	.....	.0(
12,000	0.0136	.....	.0027	32,000	0.0355	.....	.0(
14,000	0.0149	.....	.0030	200	.....	0.0139	.....
16,000	0.0170	.....	.0034	32,200	Broke at shoulder, B end.		
18,000	0.0179	.....	.0026	Diameter of fractured section, 0.798 inch			
20,000	0.0200	.....	.0040	Tenacity per square inch of original 32,200 pounds.			
200	.....	—0.0022(?)	.....				

TABLE CLXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35 A.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

2,000	0.0016	.....	.0003	20,000	0.0193	.....	.0
4,000	0.0060	.....	.0012	21,000	0.0197	.....	.0
6,000	0.0094	.....	.0019	22,000	0.0203	.....	.0
8,000	0.0124	.....	.0025	23,000	0.0207	.....	.0
10,000	0.0128	.....	.0026	23,600	Broke 1 inch from A end.		
12,000	0.0143	.....	.0029	Diameter of fractured section, 0.798 inch			
14,000	0.0161	.....	.0032	Tenacity per square inch, original section			
16,000	0.0175	.....	.0035	pounds.			
18,000	0.0180	.....	.0036				

TABLE CLXVIII.—ALLOY OF COPPER AND TIN.

Original mark: No. 35 B.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

1,200	0.0014	.....	.0003	16,000	0.0264	.....	.0
2,000	0.0040	.....	.0008	18,000	0.0281	.....	.0
3,000	0.0068	.....	.0014	20,000	0.0299	.....	.0
4,000	0.0100	.....	.0020	22,000	0.0310	.....	.0
6,000	0.0142	.....	.0028	24,000	0.0324	.....	.0
8,000	0.0178	.....	.0036	25,000	0.0329	.....	.0
10,000	0.0199	.....	.0049	25,700	Broke in middle.		
12,000	0.0224	.....	.0045	Diameter of fractured section, 0.798 inch			
14,000	0.0246	.....	.0049	Tenacity per square inch, 25,700 pounds.			

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

CHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXIX.—ALLOY OF COPPER AND TIN.

al mark: No. 36 A.—Material: Alloy.—Original mixture: 72.5 Cu, 27.5 Sn.—Rectangular section 0.998″ x 1.002″. Too brittle to be turned.

3,860 pounds, the piece broke in the upper the tensile machine, 1½ inches from A end. ain in machine. At 6,500 pounds broke in jaw, 1 inch from C end. Piece too short to ed further.	Tenacity per square inch, 6,560 pounds. Elongation not measured.

TABLE CLXX.—ALLOY OF COPPER AND TIN.

al mark: No. 36 B.—Material: Alloy.—Original mixture: 72.5 Cu, 27.5 Sn —Rectangular section, 1.010″ x 1.000″.

,550 pounds, broke in lower jaw, 1⅛ inches end. pounds, broke 3 inches from bottom, and 1 bove edge of lower jaw. pounds, broke at edge of lower jaw, 2⅛ from B end.	Breaking load, 6,550 pounds. Tenacity per square inch, 6,485 pounds. NOTE.—It appears that the brittle pieces break in the jaws of the machine partly by crushing and partly by tensile strain. The figures obtained for tenacity are, therefore, probably too low.

TABLE CLXXI.—ALLOY OF COPPER AND TIN.

al mark: No. 37 A.—Material: Alloy.—Original mixture: 67.5 Cu, 32.5 Sn.—Rectangular section, 0.975″ x 0.990″.

,606 pounds, broke in lower jaw, 1⅛ inches end. 40 pounds, broke in upper jaw, 1¼ inches end.	At 1,240 pounds, broke in upper jaw. Breaking load, 1,606 pounds. Tenacity per square inch, 1,664 pounds.

TABLE CLXXII.—ALLOY OF COPPER AND TIN.

al mark: No. 37 B.—Material: Alloy.—Original mixture: 67.5 Cu, 32.5 Sn.—Rectangular section, 0.962″ x 0.985″.

,014 pounds, broke in lower jaw by crushing. ,536 pounds, broke in upper jaw, 2 inches nd. ,334 pounds, broke in upper jaw; crushed ch. 304 pounds, broke in lower jaw, 1 inch from 408 pounds, broke in upper jaw, ¼ inch from	At 3,150 pounds, broke in upper jaw, 1¼ inches from end. At 3,330 pounds, broke in lower jaw, ¾ inch from end. Too short to test further. Breaking load (maximum), 3,330 pounds. Tenacity per square inch, 3,408 pounds.

TABLE CLXXIII.—ALLOY OF COPPER AND TIN.

al mark: No. 38 A.—Material: Alloy.—Original mixture: 62.5 Cu, 37.5 Sn.—Rectangular section 0.980″ x 0.992″.

ed 4 times; broke each time in upper jaw, 2, 2,270, 1,980, and 1,520 pounds.	Breaking load (maximum), 2,270 pounds. Tenacity per square inch, 2,335 pounds.

TABLE CLXXIV.—ALLOY OF COPPER AND TIN.

al mark: No. 38 B.—Material: Alloy.—Original mixture: 62.5 Cu, 37.5 Sn.—Rectangular section, 0.983″ x 0.990″.

e in jaws, at 766 pounds.	Tenacity per square inch, 787 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY

TABLE CLXXV.—ALLOY OF COPPER AND TIN.

Original mark: No. 39 A.—Material: Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Rectangular section: 0.982″ x 0.990″.

Tested 4 times; broke in jaws each time, at 800, 266, 1,166, and 944 pounds.	Breaking load (maximum), 1,166 pounds. Tenacity per square inch, 1,200 pounds.

TABLE CLXXVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 39 B.—Material: Alloy.—Original mixture: 57.5 Cu, 42.5 Sn.—Rectangular section 0.985″ x 0.997″.

Broke in jaws, at 966 and 1,530 pounds. Breaking load (maximum), 1,530 pounds. Tenacity per square inch, 1,553 pounds.	[No. 40 was broken by the transverse test in pieces too short for tests by tension.]

TABLE CLXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (A—C).—Material: Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.968″ x 0.985″.

Tested four times; broke in jaws each time, at 1,830, 1,730, 690, and 1,360 pounds. Tested a fifth time, when the piece broke in the middle, at 1,720 pounds.	Breaking load (maximum), 1,830 pounds. Tenacity per square inch, 1,919 pounds.

TABLE CLXXVIII.—LLOY OF COPPER AND TIN.

Original mark: No. 41 (E—D).—Material: Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.962″ x 0.985″.

At 1,340 pounds, broke 2 inches from E end. At 1,160 pounds, broke in jaws ½ inch from E end. At 1,320 pounds, broke 2 inches from D end.	Breaking load (maximum), 1,340 pounds. Tenacity per square inch, 1,414 pounds.

TABLE CLXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 41 (B—E).—Material: Alloy.—Original mixture: 47.5 Cu, 52.5 Sn.—Rectangular section, 0.960″ x 0.990″.

At 2,120 pounds, broke 1 inch from E end. At 2,750 pounds, broke 2 inches from E end.	Breaking load, 2,750 pounds. Tenacity per square inch, 2,894 pounds.

TABLE CLXXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (C—E).—Material: Alloy.—Original mixture: 42.5 Cu, 57.5 Sn.—Rectangular section, 0.992″ x 1.004″.

Tested 4 times; broke in jaws each time, at 760, 2,264, 1,470, and 1,034 pounds.	Breaking load (maximum), 2,264 pounds. Tenacity per square inch, 2,273 pounds.

TABLE CLXXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 42 (F—B).—Material: Alloy.—Original mixture, 42.5 Cu, 57.5 Sn.—Rectangular section, 0.995″ x 0.987″.

Broke at 1,890 pounds 3 inches from B end.	Tenacity per square inch, 1,924 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

ICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CLXXXII.—ALLOY OF COPPER AND TIN.

rk: No. 43 A.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

middle at 1,400 pounds. n less than 0.01 inch.	Tenacity per square inch, 2,800 pounds.

TABLE CLXXXIII.—ALLOY OF COPPER AND TIN.

rk: No. 43 B.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

nch from B end, at 1,000 pounds. n less than 0.01 inch.	Tenacity per square inch, 2,000 pounds.

TABLE CLXXXIV.—ALLOY OF COPPER AND TIN.

rk: No. 44 A.—Material: Alloy.—Original mixture: 32.5 Cu, 67.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

middle, at 796 pounds. n less than 0.01 inch.	Tenacity per square inch, 1,592 pounds.

TABLE CLXXXV.—ALLOY OF COPPER AND TIN.

rk: No. 44 B.—Material: Alloy.—Original mixture: 32.5 Cu, 67.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

shoulder, D end, at 1,526 pounds. ation detected.	Tenacity, 3,052 pounds per square inch.

TABLE CLXXXVI.—ALLOY OF COPPER AND TIN.

rk: No. 45 A.—Material: Alloy.—Original mixture: 27.5 Cu, 72.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

1,680 pounds, 1½ inches from C end.	Tenacity, 3,360 pounds per square inch.

TABLE CLXXXVII.—ALLOY OF COPPER AND TIN.

rk: No. 45 B.—Material: Alloy.—Original mixture: 27.5 Cu, 72.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

2,700 pounds, 1½ inches from D end.	Tenacity, 5,400 pounds per square inch.

TABLE CLXXXVIII.—ALLOY OF COPPER AND TIN.

rk: No. 46 A.—Material: Alloy.—Original mixture: 22.5 Cu, 77.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

2,100 pounds, 1 inch from C end. n not measured.	Tenacity, 4,200 pounds per square inch.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOL

TABLE CLXXXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 46 B.—Material: Alloy.—Original mixture: 22.5 Cu, 77.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongati parts inal le
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
800	0.0015	.....	.0003	4,000	0.0164	.....	.0
1,600	0.0058	.....	.0012	5,000	0.0182	.....	.0
2,000	0.0070	.....	.0014	5,800	0.0213	.....	.0
2,400	0.0090	.....	.0018	Broke just as beam rose 1½ inches from			
2,800	0.0109	.....	.0022	Diameter of fractured section, 0.796 inc			
3,200	0.0124	.....	.0025	Tenacity per square inch of original			
3,600	0.0140	.....	.0027	5,800 pounds.			
4,000	0.0157	.....	.0031	Tenacity per square inch of fractured			
200	.....	0.0096	.....	5,827 pounds.			

TABLE CXC.—ALLOY OF COPPER AND TIN.

No. 47 A.—Broke in handling.

ALLOY OF COPPER AND TIN.

Original mark: No. 47 B.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

Broke at 1,408 pounds, 1½ inches from D end. Elongation not measured. Tenacity, 2,816 pounds per square inch.	Diameter of fractured section, 0.797 inc Tenacity per square inch of fractured 2,822 pounds.

TABLE CXCI.—ALLOY OF COPPER AND TIN.

Original mark: No. 48 A.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

Broke in middle, at 1,708 pounds. Elongation not measured. Diameter of fractured section, 0.795 inch.	Tenacity per square inch of original 3,416 pounds. Tenacity per square inch of fractured 3,440 pounds.

TABLE CXCII.—ALLOY OF COPPER AND TIN.

Original mark: No. 48 B.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Dimensions: 5″. Diameter, 0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Diameter of fractured section, 0.795 incl Tenacity per square inch, original secti pounds. Tenacity per square inch, fractured secti pounds.
Pounds.	*Inches.*	*Inches.*		
800	0.0022	.....	.0004	
1,600	0.0097	.....	.0019	
2,000	0.0160	.....	.0032	
2,400	0.0224	.....	.0045	
200	.....	0.0172	.....	
2,800	0.0310	.....	.0062	
3,200	0.0407	.....	.0081	
4,000	0.0551	.....	.0110	
200	.....	0.0496	.....	
4,180	Broke in middle.			

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

ANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCIII.—ALLOY OF COPPER AND TIN.

nark: No. 49 A.—Material: Alloy.—Original mixture: 7.5 Cu, 92.5 Sn.—Dimensions: Length, 5″.—Diameter, 0.798″.

r e	Elongation in 5 inches.	Set.	Elongation in parts of original length.
	Inches.	*Inches.*	
	0.0065	.....	.0013
	0.0278	.....	.0056
	.....	0.0247	.....
	0.0472	.....	.0094
	0.1109	.....	.0222
	0.7943	.....	.1589
	of piece corrugated by strain. Reduced		
	0.8709	.....	.1742
	Broke in middle.		

Breaking load, 6,192 pounds per square inch.
Diameter of fractured section, 0.710 inch.
Tenacity per square inch of original section, 6,192 pounds.
Tenacity per square inch, fractured section (assuming that the final section sustained the last recorded load, 5,000 pounds per square inch original section), 6,315 pounds. Dividing the maximum load by the final area, the apparent tenacity per square inch of fractured section is 7,981 pounds.

TABLE CXCIV.—ALLOY OF COPPER AND TIN.

nark: No. 49 B.—Material: Alloy.—Original mixture: 7.5 Cu, 92.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″.

r e	Elongation in 5 inches.	Set.	Elongation in parts of original length.
	Inches.	*Inches.*	
	0.0019	.....	.0004
	0.0067	.....	.0013
	0.0121	.....	.0024
	.....	0.0066	.....
	0.0176	.....	.0035
	0.0265	.....	.0053
	0.0335	.....	.0067
	0.0440	.....	.0088
	.....	0.0420	.....
	0.0510	.....	.0102
	0.0633	.....	.0127
	0.0905	.....	.0181
	0.1245	.....	.0249
	0.1815	.....	.0364
	Continued 3 minutes; piece extended		
y	broke. Last reading of elongation,		
e	fracture, 1.1508 inches, 23.02.		

Diameter of fractured section, 0.680 inch.
Tensile strength per square inch, original section, 6,000 pounds.
Tensile strength per square inch, fractured section, 8,260 pounds.

TABLE CXCV.—ALLOY OF COPPER AND TIN.

ıark: No. 50 A.—Material: Alloy.—Original mixture: 2.5 Cu, 97.5 Sn.—Dimensions: Length, 5″. Diameter, 0.798″

r e	Elongation in 6 inches.	Set.	Elongation in parts of original length.
	Inches.	*Inches.*	
	0.0061	.....	.0012
	0.0124	.....	.0025
	0.0236	.....	.0047
	0.0356	.....	.0071
	0.0493	.....	.0099
	0.0596	.....	.0119
	0.0691	.....	.0138
	0.0926	.....	.0185
	0.1158	.....	.0232
	0.1601	.....	.0320
	0.2496	.....	.0499
	0.4391	.....	.0878
	Continued 2 minutes. Elongation		

increased to 1.8260 or 36.52 per cent., when the micrometer would not follow it further. The resistance to strain then gradually decreased to 2,200 pounds per square inch, when the piece broke in the middle. Total elongation measured after fracture, 2.05 inches; per cent. of length, 41.00.
Diameter of fractured section, 0.545 inch.
Tensile strength per square inch of original section, 5,600 pounds.
Tensile strength per square inch of fractured section (assuming that the final section sustained the last observed load, viz, 1,100 pounds), 4,500 pounds.
Dividing the maximum load (2,800 pounds) by the final area, the apparent tenacity per square inch of fractured section is 12,002 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

[*Second series.*]

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CXCVI.—ALLOY OF COPPER AND TIN.

Original mark: No. 50 B.—Material: Alloy.—Original mixture: 2.5 Cu, 97.5 Sn.—Dimensions: Len 5". Diameter: 0.798".

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1,200	0.0057	.....	.0011
2,000	0.0255	.....	.0051
200	.....	0.0195	.....
2,400	0.0347	.....	.0069
2,800	0.0460	.....	.0092
3,200	0.0515	.....	.0103
3,600	0.0707	.....	.0141
4,000	0.0775	.....	.0155
200	.....	0.0757	.....
4,400	0.0945	.....	.0189
4,800	0.1275	.....	.0255
5,200	0.1900	.....	.0380
5,600	0.3275	.....	.0655
5,600	Continued 2 minutes.		
Piece extended rapidly.			
Resistance decreased to 5,000, at which it continued for 1 minute.			
5,000	1.8120	.....	.3624

Resistance decreased further and piece bro inches from B end.
Total extension measured after breaking inches; per cent. of length, 39.00.
Diameter of fractured section, 0.530 inch.
Tenacity per square inch of original section, pounds.
Tenacity per square inch of fractured se (dividing maximum load by final area), pounds.

RECORD OF TESTS BY COMPRESSIVE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTEOF TECHNOLO

TABLE CXCVII.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Material: Cast copper.—Laboratory number: 525.—Dimensions: Length, 2". Diameter: 0.62

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compres parts of nal leng
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
1,000	0.002	3,259	.0010	13,000	0.345	42,373	.17
2,000	0.007	6,519	.0035	14,000	0.415	45,633	.20
3,000	0.010	9,778	.0050	15,000	0.474	48,892	.23
4,000	0.015	13,038	.0075	16,000	0.552	52,152	.27
5,000	0.019	16,297	.0095	16,500	0.581	53,782	.29
6,000	0.022	19,557	.0110	17,000	0.611	55,411	.30
7,000	0.028	22,816	.0140	17,500	0.648	57,041	.32
8,000	0.048	26,076	.0240	22,000	1.26	71.709	.63
9,000	0.092	29,335	.0460	Removed piece.			
10,000	0.146	32,595	.0730	At 9,000 pounds a slight double curve w served; at 10,000 the resistance decreas			
11,000	0.201	35,854	.1005	9,700 in 2 minutes.			
12,000	0.279	39,114	.1395				

RECORD OF TESTS BY TORSIONAL STRESS.

[*Second series.*]

TABLE CXCVIII.—COPPER AND TIN ALLOYS.

RESULTS OF TESTS, CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAMS.

Number.	Area of diagram.	Angle of torsion.	Ordinate.		Torsional moment.		Ductility extension of exterior fiber.	Resilience.	Remarks.		
			Maximum.	At elastic limit.	Maximum.	At elastic limit.					
	Sq. in.	*Degrees.*	*Inches.*	*Inches.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*			
31 A ..	3.55	53	0.85	0.30	89.69	34.24	0.0409	66.14	Defective bar.		
B ..	0.80	29	0.35	0.20	39.28	24.16	0.0124	16.10	Defective bar.		
C ..	1.46	28	0.65	0.30	69.53	34.24	0.0116	27.64	Defective bar.		
D ..	1.97	41	0.63	0.30	67.51	34.24	0.0247	37.51	Defective bar.		
32 A ..	20.99	204	1.45	0.40	150.17	44.32	0.4960	383.45			
B ..	20.41	207	1.50	0.40	155.22	44.32	0.5082	373.46			
C ..	16.75	153	1.50	0.50	155.82	55.27	0.3024	306.32			
D ..	22.58	185	1.60	0.60	165.30	64.49	0.4206	410.10			
33 A ..	9.96	73	1.75	0.65	180.42	69.53	0.0763	180.29			
B ..	6.72	55	1.55	0.60	160.85	65.33	0.0440	122.29			
C ..	11.65	82	1.80	0.70	185.46	74.57	0.0055	210.65			
D ..	10.38	73	1.80	0.60	185.46	64.49	0.0763	187.68			
34 A ..	1.91	14	1.90	0.90	195.54	94.73	0.0029	34.57			
B ..	1.66	13	1.95	0.90	200.58	94.73	0.0025	30.11			
C ..	3.51	21	2.15	1.00	220.74	104.81	0.0065	63.21			
D ..	0.85	8	1.70	1.10	175.38	114.89	0.0010	15.51			
35 A ..	0.32	4	1.50	1.40	155.22	145.13	0.0002	5.91			
B ..	0.61	5.5	2.10	1.60	215.70	165.29	0.0004	11.11			
C ..	0.31	5	1.00	0.80	104.81	84.65	0.0004	5.80			
D ..	0.16	3	1.35	0.40	140.09	44.32	0.0001	3.02			
									Diameter.	Equivalent torsional moment, standard size.	
									Inches.		
36 A ..	0.10	1	3.25	3.25	138.76	138.76	0.00003	0.76	0.975	26.56	
B ..	0.05	1	1.28	1.28	133.04	133.04	0.00003	0.91	0.980	24.51	
37 A ..	0.18	1.5	2.45	2.45	105.03	105.03	0.00008	1.37	0.970	29.10	
B ..	0.10	1.8	2.55	2.55	109.25	109.25	0.0001	0.79	*	*24.15	
38 A ..	0.03	0.5	2.15	2.15	134.54	134.54	0.00001	0.24	0.975	25.44	
B ..	0.005	0.4	0.20	0.20	10.19	10.19	0.00001	0.05	0.945	2.25	
39 — ..	0.02	0.5	0.63	0.63	28.32	28.32	0.00001	0.16	0.980	3.69	
40 A ..	0.002	0.3	0.50	0.50	22.84	22.84	0.00001	0.02	0.935	6.32	
B ..	0.016	0.5	0.65	0.65	29.16	29.16	0.00001	0.14	0.935	8.71	
41 A ..	0.025	1	1.30	1.30	58.56	58.56	0.00001	0.29	0.930	17.17	
B ..	0.06	1	1.40	1.40	62.78	62.78	0.00002	0.67	0.925	18.75	
42 A ..	0.06	1	1.75	1.75	75.53	75.53	0.00001	0.67	0.960	20.84	
B ..	0.12	2	1.30	1.30	56.56	56.56	0.00013	0.96	0.950	16.11	
C ..	0.05	1	1.00	1.00	43.91	43.91	0.00002	0.09	0.975	11.75	
43 A ..	0.07	1.5	0.80	0.80	12.39	12.39	0.00004	0.26			
B ..	0.06	2	0.45	0.45	6.92	6.92	0.00005	0.19			
C ..	0.06	1	0.20	0.20	16.59	16.59	0.00002	0.20			
D ..	0.05	1.5	0.70	0.70	12.09	12.09	0.00005	0.13			
44 A ..	0.03	1	0.60	0.60	6.92	6.92	0.00002	0.11			
B ..	0.60	5	1.75	1.70	28.29	28.30	0.0004	1.49			
C ..	0.22	3	0.25	0.25	17.35	17.35	0.0001	0.75			
D ..	0.05	1.5	0.80	0.80	14.79	14.79	0.00004	0.13			
45 A ..	0.07	1.5	0.80	0.80	14.79	14.79	0.00004	0.24			
C ..	0.75	15	2.15	1.35	34.20	33.46	0.0004	2.14			
D ..	0.14	2.5	1.50	1.50	28.76	28.76	0.0001	0.70			

RECORD OF TESTS BY TORSIONAL STRESS—Continued.

	Number.	Area of diagram.	Angle of torsion.	Ordinate. Maximum.	Ordinate. At elastic limit.	Torsional moment. Maximum.	Torsional moment. At elastic limit.	Ductility: extension of exterior fiber.	Resilience.	Remarks.
		Sq. in.	*Degrees*	*Inches.*	*Inches.*	*Ft.-lbs.*	*Ft.-lbs.*		*Ft.-lbs.*	
No weight on arm.	46 A ..	0.26	3.5	0.95	0.95	17.35	17.35	0.0002	0.84	
	B ..	2.73	16	1.90	1.80	33.56	31.29	0.0038	8.45	
	C ..	0.87	6	1.85	1.80	32.71	31.29	0.0005	2.71	
	D ..	0.39	4	1.55	1.45	27.59	25.88	0.0002	1.24	
	47 A ..	0.18	3	0.95	0.90	17.35	15.98	0.0001	0.60	
	B ..	1.70	13	1.55	1.10	27.59	19.49	0.0025	5.32	
	C ..	1.08	10.5	1.40	1.12	25.03	19.73	0.0016	3.33	
	D ..	2.11	16	1.55	1.30	27.59	23.33	0.0038	6.60	
No weight on arm of machine.	48 A ..	6.75	53	1.35	1.07	24.18	18.97	0.0409	21.16	
	B ..	8.51	64	1.43	1.15	25.54	20.34	0.0592	26.62	
	C ..	7.97	63	1.35	1.10	24.18	19.48	0.0574	24.99	
	D ..	6.05	46	1.43	1.05	25.54	18.63	0.0310	18.93	
	49 A ..	10.73	125	1.00	0.60	18.21	12.38	0.2103	34.44	
	B ..	15.30	186	0.90	0.50	16.50	9.67	0.4245	49.26	
	C ..	19.24	180	1.45	0.60	25.89	12.38	0.4014	60.88	Rapid moti
	D ..	18.02	221	1.03	0.50	18.71	9.67	0.5662	58.06	
	50 A ..	22.45	325	0.82	0.55	15.22	10.53	1.0352	73.32	
	B ..	21.33	348	0.80	0.30	14.79	6.26	1.1453	* 70.45	
	C ..	25.92	350	1.00	0.40	18.21	6.83	1.1550	84.15	
	D ..	28.28	424	0.80	0.30	14.79	6.26	1.5400	92.66	

* Rectangular section 0.970″ × 0.975″, reduced to standard section by the formula—

$$V = \frac{\frac{1}{2}\pi r^3}{\frac{1}{4.242} b^3} = V \times .221.$$ V = value of specimen tested. b = side of square specimen. $r = 0.3$

RECORD OF TESTS BY TRANSVERSE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLO

TABLE CXCIX.—BAR OF CAST COPPER.

Original mark: No. 53.—Material: Copper cast in iron mold.—Dimensions: Length between sup $l = 22''$. Breadth, 1.0″. Depth, 1.0″.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4 \Delta bd^3}$	Load.	Deflection. Δ	Set.	Modulu elastici $\frac{Pl^3}{4 \Delta b}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
13	0.0053	.....	6,529,433	3	.....	0.0150	.....
23	0.0095	.....	6,444,841	343	0.0970	.....	10,443.
43	0.0165	.....	6,937,333	393	0.1130	.....	9,258.
63	0.0245	.....	6,845,142	433	0.1305	.....	8,832.
83	0.0315	.....	7,014,158	493	0.1765	.....	.....
93	0.0335	.....	7,390,029	543	0.2375	.....	.....
3	.....	0.0085	.....	593	0.3335	.....	.....
113	0.0385	.....	7,813,142	643	0.46	.....	.....
153	0.0495	.....	8,227,114	743	0.84	.....	.....
193	0.0590	.....	8,707,912	843	1.38	.....	.....
3	.....	0.0100	.....	893	Broke in applying strain.		
213	0.0630	.....	9,000,094	Breaking load, about 860 pounds.			
253	0.0735	.....	9,163,075	Modulus of rupture, $R = \frac{3}{2} \frac{Pl}{bd^2} = 28,380.$			
293	0.0830	.....	9,397,187				

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CC.—BAR OF CAST COPPER.

l mark: No. 54.—Material: Copper, cast in iron mold.—Dimensions: $l = 22''$. $b = 1''$. $d = 1''$.

Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\ \Delta\ bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\ \Delta\ bd^3}$
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0.0025		13,842,400	443	1.22		
0.0046		13,310,000	493	1.68		
0.0098		11,680,204	543	2.18		
0.0165		11,777,333	593	2.90		
0.0210		11,788,856	643	The supports slid from under the bar as it bent under the load. The piece was afterwards bent by pressure at the ends till the ends touched without breaking.		
0.0370		10,288,270				
0.0620		8,551,503				
0.1120						
	0.0560					
0.2400						
0.4700						
0.80						

Breaking load, $P = 643$ pounds.

Modulus of rupture, $R = \frac{3\ Pl}{2\ ba^2} = 21,219$.

TABLE CCI.—BAR OF CAST COPPER.

l mark: No. 55.—Material: Copper, cast in iron mold.—Dimensions: Length between supports, $l = 22''$. Breadth, $b = 0.985''$. Depth, $d = 0.970.''$

0.0033			480	0.4088		
0.0075		15,792,947	500	0.4855		
0.0176		13,459,739	5		0.3619	
0.0224		13,219,331	540	0.6343		
	0.0001		580	0.8378		
0.0337		12,301,425	Ruptured.			
0.0477		11,174.068	580	0.8653		
0.0552		10,728,725	680	1.46		
	0.0095		720	1.74		
0.0674		10,540,763	800	2.39		
0.0910		9,111,146	840	2.85		
0.1176			860	3.23		
0.1553			Supports slid out. Bar bent.			
0.2057			Breaking load, $P = 860$ pounds.			
	0.1114		Modulus of rupture, $R = \frac{3\ Pl}{2\ bd^2} = 30,621$.			
0.2883						

TABLE CCII.—BAR OF CAST COPPER.

mark: No. 56.—Material: Copper cast in iron mold.—Dimensions: $l = 22''$. $b = 0.972''$. $d = 0.955''$.

0.0088		14,293,526	480	1.30		
0.0191		13,170,088	500	1.47		
0.0261		12,047,347	520	1.65		
	0.0048		540	1.81		
0.0452		9,739,155	560	2.01		
0.0606		9,339,672	580	2.21		
0.0861		7,303,964	600	2.41		
	0.0402		620	2.66		
0.1302			640	3.51		
0.2247			Supports slid out. Bar bent.			
0.3628			Breaking load, $P = 640$ pounds.			
0.5397			Modulus of rupture, $R = \frac{3\ Pl}{2\ ba^2} = 23,834$.			
0.7752						
	0.6702					
1.01						

RECORD OF TESTS BY TRANSVERSE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCIII.—BAR OF CAST COPPER.

Original mark: No. 57.—Material: Lake Superior copper cast in iron mold.—Dimensions: Leng between supports, $l=22''$. $b=1.010''$. $d=1.010''$.

Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\ \Delta\ bd^3}$	Load.	Deflection. Δ	Set.	Modulus of elasticity. $\frac{Pl^3}{4\ \Delta\ bd^3}$
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
10	0.0068			600	1.1248		
20	0.0099		5,168,758	3		0.9840	
40	0.0148		6,914,865	Resistance increased in 15 minutes to 10 pound			
80	0.0232		8,822,534	3		0.9832	
100	0.0280		9,137,625	Decrease of set in 15 minutes.		0.0008	
3		0.0084		600	1.1483		
150	0.0401		9,036,856	620	1.22		
200	0.0538		9,511,283	640	1.40		
250	0.0680		9,406,380	680	1.75		
300	0.0889		8,633,976	720	2.10		
350	0.1193		7,506,180	760	2.48		
400	0.1670		6,128,228	800	3.22		
3		0.0812		820	3.77		
420	0.1908			Bent without breaking.			
450	0.2798			Breaking load, $P=820$ pounds.			
500	0.4910			Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=26,271.$			
520	0.5898						
540	0.7110						
560	0.9913						

TABLE CCIV.—BAR OF CAST TIN.

Original mark: No. 58.—Material: Queensland tin cast in iron mold.—Dimensions: $l=22''$. $b=1.0$ $d=1.023''$.

10	0.0082		
20	0.0118		5,754,991
3		0.0009	
10	0.0087		
20	0.0129		
30	0.0173		5,310,020
40	0.0241		5,635,593
50	0.0333		3,596,764
3		0.0126	
60	0.0502		
70	0.0600		
80	0.0859		
90	0.1416		
100	0.2109		
3		0.1753	
100	0.2415		
Resistance decreased in 1 minute to 70 pounds.			
Resistance decreased in 3 minutes to 62 pound			
Resistance decreased in 8 minutes to 56 pound			
100	0.3033		
110	0.3827		
120	0.6403		
130	0.8091		
130 Cont'd 1 min.	1.07		
140	1.36		
150	Ran pressure-screw down slowly till flection was more than 3 inches; the scale-be vibrating all the time about 150 pounds.		
Bent without breaking.			
Breaking load, $P=150$ pounds.			
Modulus of rupture, $R=\frac{3}{2}\frac{Pl}{bd^2}=4,559.$			

RECORD OF TESTS BY TENSILE STRESS.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCV.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Original mark: No. 51 A.—Material: Copper cast in hot iron mold, fluxed with fluor spar.—Dime sions: Length, 6.12". Diameter, 0.798".

Load per square inch.	Elongation in 6.12 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
6,980	0.01		.0016
8,480	0.02		.0033
9,840	0.03		.0049
10,700	0.04		.0065
11,560	0.06		.0098
11,800	0.07		.0114
12,310	0.09		.0147
13,560	0.12		.0196
14,440	0.16		.0261
14,540	Broke 1 inch from C end.		

Fractured section elliptical.
Diameters, 0.770 and 0.780 inch.
Tenacity per square inch, original section, 14,
pounds.
Tenacity per square inch, fractured secti
15,412 pounds.

RECORD OF TESTS BY TENSILE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCVI.—CAST COPPER (FLUXED WITH FLUOR SPAR).

Original mark: No. 51 B.—Material: Copper, cast in hot iron mold fluxed with fluor spar.—Dimensions: Length, 6.19″. Diameter, 0.798″.

ad per quare ch.	Elongation in 6.19 inches.	Set.	Elongation in parts of original length.
unds.	*Inches.*	*Inches.*	
8,000	0.01	.....	.0016
9,800	0.02	.....	.0032
10,000	0.03	.....	.0048
11,400	0.07	.....	.0113
12,400	0.11	.....	.0178
15,100	0.17	.....	.0275
16,200	0.23	.....	.0372
17,040	0.26	.....	.0258
18,000	0.30	.....	.0485
19,400	0.36	.....	.0581
20,000	0.40	.....	.0646
0	.....	0.40	.....
20,400	0.44	.....	.0710
20,440	0.46	.....	.0743

Broke at D end.

Diameter of fractured section, 0.763 inch.

Tenacity per square inch, original section, 20,440 pounds.

Tenacity per square inch, fractured section, 22,353 pounds.

The following measurements were made of the diameter of the piece after breaking:

	Inches.
At fractured section	0.763
½ inch from fractured section	0.765
1 inch from fractured section	0.766
2 inches from fractured section	0.766
3 inches from fractured section	0.765
4 inches from fractured section	0.766
4½ inches from fractured section	0.767
5 inches from fractured section	0.768
6 inches from fractured section	0.768
6½ inches from fractured section	0.774

TABLE CCVII.—CAST COPPER.

Original mark: No. 52 A.—Material: Copper cast in iron mold.—Dimensions: Length, 5.95″. Diameter, 0.798″.

ad per quare ch.	Elongation in 5.95 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5.95 inches.	Set.	Elongation in parts of original length.
unds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
200	0.0008	.....	.0001	11,700	0.0272	.....	.0046
1,800	0.0012	.....	.0002	12,000	0.0315	.....	.0053
2,800	0.0023	.....	.0004	200	.....	0.0232	.....
3,700	0.0037	.....	.0006	12,400	0.0373	.....	.0063
200	.....	0.0002	.....	13,450	0.0439	.....	.0074
4,000	0.0042	.....	.0007	200	.....	0.0353	.....
4,800	0.0048	.....	.0008	14,040	0.0510	.....	.0086
200	.....	0.0004	.....	14,850	0.0628	.....	.0106
6,100	0.0066	.....	.0011	16,000	0.0853	.....	.0143
7,100	0.0080	.....	.0013	200	.....	0.0743	.....
7,700	0.0093	.....	.0016	16,940	0.0953	.....	.0160
200	.....	0.0023	.....	Broke.			
8,000	0.0102	.....	.0017	Diameter of fractured section, 0.775 inch.			
8,950	0.0129	.....	.0022	Tenacity per square inch, original section, 16,940 pounds.			
9,800	0.0158	.....	.0027	Tenacity per square inch, fractured section, 17,956 pounds.			
200	.....	0.0084	.....				
10,300	0.0195	.....	.0033				

RECORD OF TESTS BY TENSILE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLO

TABLE CCVIII.—CAST COPPER.

Original mark: No. 52 B.—Material: Copper cast in iron mold.—Dimensions: Length, 5″. Di
0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
1,200	0.0018	.....	.0004
2,000	0.0024	.....	.0005
4,000	0.0028	.....	.0006
8,000	0.0050	.....	.0010
8,800	0.0068	.....	.0014
9,600	0.0100	.....	.0020
10,400	0.0180	.....	.0036
11,200	0.0284	.....	.0057
12,000	0.0467	.....	.0093
12,800	0.0658	.....	.0132
13,600	0.0932	.....	.0186
14,400	0.1250	.....	.0250
15,200	0.1607	.....	.0321
16,000	0.1984	.....	.0397
16,800	0.2347	.....	.0469

Load per square inch.	Elongation in 5 inches.	Set.	Elongat parts inal l
Pounds	*Inches.*	*Inches.*	
17,600	0.2837	.....	.0
18,400	0.3236	.....	.0
200	.....	0.3122	.....
19,200	0.3752	.....	.0
20,000	0.4078	.....	.0
20,800	0.4402	.....	.0
21,200	0.4582	.....	.0
21,600	Broke in middle.		

Fractured section elliptical. Diameters, 0
0.707 inch.
Tenacity per square inch, original sectio
pounds.
Tenacity per square inch, fractured
27,204 pounds.

TABLE CCIX.—CAST COPPER.

Original mark: No. 53 A.—Material: Copper cast in iron mold.—Dimensions: Length, 5″. Di
0.798″.

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Pounds.	*Inches.*	*Inches.*	
12,800	0.0135	.....	.0027
13,600	0.0167	.....	.0033
14,400	0.0225	.....	.0045
15,200	0.0310	.....	.0062
16,000	0.0421	.....	.0084
16,800	0.0535	.....	.0107
17,600	0.0664	.....	.0133
18,000	0.0744	.....	.0149
18,400	0.0818	.....	.0163
18,800	Broke 1 inch from A end.		

Diameter of fractured section, 0.780 inch.
Fractured surface spongy, full of blowho
Tenacity per square inch, original sectio
pounds.
Tenacity per square inch, fractured
19,673 pounds.

TABLE CCX.—CAST COPPER.

Original mark: No. 53 B.—Material: Copper, cast in iron mold.—Dimensions: Length, 5″. Di
0.798″.

Broke at 9,200 pounds per square inch. The piece bent while it was being strained so that the elongations could not be determined.

The piece was spongy and full of blo
throughout.

RECORD OF TESTS BY TENSILE STRESS—Continued.

NICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXI.—OF CAST COPPER.

ark: No. 57 A.—Material: Copper cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0. 0009	.....	.0002	18, 000	0. 1507	.....	.0301
0 0018	.....	.0003	19, 000	0. 1806	.....	.0361
0. 0066	.....	.0013	20, 000	0. 2122	.....	.0424
0. 0089	.....	.0018	240	.....	0. 2009	.....
0. 0113	.....	.0023	21, 000	0. 2455	.....	.0491
0. 0137	.....	.0027	22, 000	0. 2824	.....	.0566
0. 0168	.....	.0034	24, 000	0. 3205	.....	.0641
0. 0205	.....	.0041	24, 000	0. 3686	.....	.0737
.....	0. 0089	.....	240	.....	0. 3551	.....
0. 0234	.....	.0047	25, 000	0. 4180	.....	.0836
0. 0279	.....	.0056	26, 000	0. 4670	.....	.0934
0. 0335	.....	.0067				
0. 0402	.....	.0080	Broke in middle.			
.....	0. 0324	.....	Diameter of fractured section, 0.738 inch.			
0. 0492	.....	.0098	One elliptical blowhole in fractured surface.			
0. 0627	.....	.0125	Diameters, 0.48 and 0.08 inch.			
0. 0798	.....	.0160	Tenacity per square inch, original section, 26,000 pounds.			
0. 1041	.....	.0208	Tenacity per square inch, fractured section, 30,392 pounds.			
.....	0. 0964	.....				
0. 1277	.....	.0255				

TABLE CCXII.—CAST COPPER.

ark: No. 57 B.—Material: Copper cast in iron mold.—Dimensions: Length, 5″. Diameter, 0.798″.

Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches	Set.	Elongation in parts of original length.
Inches.	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
0. 0004	.....	.0001	17, 000	0. 0779	.....	.0156
0. 0032	.....	.0006	18, 000	0. 0951	.....	.0190
0. 0064	.....	.0013	19, 000	0. 1142	.....	.0228
0. 0093	.....	.0019	20, 000	0. 1388	.....	.0278
0. 0116	.....	.0023	240	.....	0. 1317	.....
0. 0144	.....	.0029	21, 000	0. 1702	.....	.0340
0. 0170	.....	.0034	22, 000	0. 2 28	.....	.0406
0. 0201	.....	.0040	24, 000	0. 2444	.....	.0489
.....	0. 0037	.....	24, 000	0. 3020	.....	.0604
0. 0227	.....	.0045	240	.....	0. 2933	.....
0. 0263	.....	.0053	25, 000	0. 3585	.....	.0717
0. 0321	.....	.0064	26, 000	Measuring apparatus slipped.		
0. 0371	.....	.0074	29, 820	Broke 2 inches from B end.		
.....	0. 0253	.....	Diameter of fractured section, 0.724 inch.			
0. 0428	.....	.0086	Tenacity per square inch, original section, 29,820 pounds.			
0. 0485	.....	.0097	Tenacity per square inch, fractured section, 36,217 pounds.			
0. 0554	.....	.0111				
0. 0652	.....	.0130				
.....	0. 0583	.....				

RECORD OF TESTS BY TENSILE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNO:

TABLE CCXIII.—QUEENSLAND TIN, CAST.

Original mark: No. 58 A.—Material: Tin cast in iron mold. Dimensions: Length, 5". D
0.798".

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length.	Load per square inch.	Elongation in 5 inches.	Set.	Elongati parts nal le
Pounds.	*Inches.*	*Inches.*		*Minutes.*	*Inches.*	*Pounds*	
400	0. 0002	.....	.00004	7	0. 1861	.....	.....
600	0. 0027	.....	.0005	8	0. 1997	.....	.....
800	0. 0081	.....	.0016	9	0. 2176	.....	.....
1, 000	0. 0175	.....	.0035	10	0. 2328	.....	.....
240	.....	0. 0159	.....	11	0. 2490	.....	.....
1, 200	0. 0309	.....	.0062	12	0. 2687	.....	.....
1, 400	0. 0433	.....	.0086	13	0. 2929	.....	.....
1, 600	0. 0517	.....	.0103	14	0. 3311	.....	.....
1, 800	0. 0630	.....	.0126	Resistance reduced to 1,700 pounds pe			
2, 000	0. 0745	.....	.0149	inch, and a crack was observed on one si			
240	.....	0. 0756	.....	1, 700 lbs.	0. 3610	.....	.(
2, 000	0. 0860	.....	.0172	1 min.	0. 4315	.....	.(
2,000 pounds per square inch kept constant for 14 minutes, elongation increasing as follows:				Resistance decreased gradually, and pie			
Minutes.				2 inches from A end.			
1	0. 1070	.....	.....	The fractured surface had an irregula			
2	0. 1156	.....	.....	ary nearly elliptical; two diameters			
3	0. 1298	.....	.....	0.580 and 0.685 inch			
4	0. 1437	.....	.....	Tensile strength per square inch, ori			
5	0. 1580	.....	.....	tion, under slow strain, 2,000 pounds.			
6	0. 1709	.....	.....	Total time of test, 30 minutes.			

TABLE CCXIV.—QUEENSLAND TIN, CAST.

Original mark: No. 58 B.—Material: Tin cast in iron mold. Dimensions: Length, 5". 1
0.798".

Load per square inch.	Elongation in 5 inches.	Set.	Elongation in parts of original length	Load per square inch.	Elongation in 5 inches.	Set.	Elongi part nal l
Pounds.	*Inches.*	*Inches.*		*Pounds.*	*Inches.*	*Inches.*	
400	0. 0005	.....	.0001	2, 000	0. 0631	.....	
600	0. 0029	.....	.0006	Stress kept constant for 2 minutes.			
800	0. 0051	.....	.0010	1 min.	0. 0724	.....	
1, 000	0. 0108	.....	.0022	2 min.	0. 0821	.....	
1, 200	0. 0184	.....	.0037	Increased stress rapidly for 1 minute,			
1, 400	0. 0293	.....	.0059	broke at 3,520 pounds per square inch.			
1, 600	0. 0394	.....	.0079	Total time of test, 8 minutes.			
1, 800	0. 0484	.....	.0097	Diameter of fractured section 0.542 i			
2, 000	0. 0566	.....	.0113	Tensile strength per square inch, origi			
240	.....	0. 0557	.....	under rapid strain, 3,520 pounds.			

'S BY TORSIONAL STRESS OF EXTRA PIECES OF COPPER AND TIN.

CALCULATED FROM THE AUTOGRAPHIC STRAIN DIAGRAMS.

TABLE CCXV.—LAKE SUPERIOR COPPER.

Area of diagram.	Angle of torsion.	Maximum ordinate.	Ordinate at elastic limit.	Maximum torsional moment.	Torsional moment at elastic limit.	Extension of exterior fibre.	Resilience.
Sq. inches.	°	*Inches.*	*Inches.*	*Ft.-pounds.*	*Ft.-pounds.*		*Ft.-pounds.*
6.90	128	0.65	0.18	87.19	32.00	0.2196	165.65
21.18	135	1.90	0.70	134.38	52.94	0.2418	263.58
10.58	168.5	0.80	0.35	104.81	51.96	0.3582	248.74
5.29	113	0.85	0.20	110.68	34.34	0.1747	129.81
13.16	185	1.05	0.15	134.17	28.47	0.4206	304.75
8.75	109	0.96	0.42	100.78	43.64	0.1634	199.97
15.63	170	1.20	0.27	124.97	31.22	0.3637	352.53
7.58	82	1.15	0.35	119.93	39.28	0.0954	170.88
2.72	47	0.80	0.35	84.65	39.28	0.0323	64.65
2.70	40	0.80	0.40	84.65	44.32	0.0235	62.91
2.70	39	0.85	0.40	89.69	44.32	0.0224	62.72
4.29	72	0.70	0.20	74.57	24.16	0.0743	80.49
15.44	160	1.15	0.50	119.93	54.41	0.3272	282.76
7.84	98	0.95	0.40	99.77	44.32	0.1339	144.75
9.35	115	1.00	0.30	104.81	34.24	0.1804	172.49

TABLE CCXVI.—QUEENSLAND TIN.

34.78	619	0.65	0.20	11.73	4.08	2.5211	176.21
65.55	818	0.95	0.25	16.84	4.93	3.5722	291.04
28.00	637	0.60	0.20	10.88	4.08	2.6154	158.20

RECORD OF TESTS BY COMPRESSIVE STRESS.

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXVII.—ALLOY OF COPPER AND TIN.

l mark: No. 31.—Material: Alloy.—Original mixture: 97.5 Cu, 2.5 Sn.—Analysis: 99.09 Cu, 0.87 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Inches.	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
.0000	.....	.....	16,000	.3951	52,152	.1975
.0018	6,519	.0009	18,000	.5176	58,671	.2588
.0093	13,038	.0046	20,000	.6156	65,188	.3078
.0302	19,557	.0151	22,000	.7266	71,709	.3633
.0609	26,075	.0305	24,000	.8483	78,228	.4242
.1077	32,595	.0539	25,000	.8801*	81,485	.4100
.1662	39,114	.0831				
.2601	45,633	.1300				

*Wedge cracked off at the top.

CCXVIII:—ALLOY OF COPPER AND TIN.

l mark: No. 32.—Material: Alloy.—Original mixture: 92.5 Cu, 7.5 Sn.—Analysis: 94.11 Cu, 5.43 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

.0000	.....	.....	22,000	.4584	71,709	.2292
.0000	6,519	.....	24,000	.5151	78,228	.2575
.0000	13,038	.....	26,000	.5778	84,747	.2889
.0002	19,557	.0001	28,000	.6393	91,266	.3197
.0108	26,075	.0054	30,000	.7000	97,780	.3500
.0511	32,595	.0255	32,000	.7499	104,303	.3749
.1219	39,114	.0609	34,000	.8033	110,822	.4016
.1937	45,633	.0968	36,000	.8447	117,341	.4223
.2648	52,152	.1324	38,000	.8918	123,860	.4459
.3310	58,671	.1655	40,000	.9330	130,379	.4665
.3951	65,188	.1975				

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXIX.—ALLOY OF COPPER AND TIN.

Original mark: No. 33.—Material: Alloy.—Original mixture: 87.5 Cu, 12.5 Sn.—Analysis: 88.40 Cu, 11.59 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	.....	.....	24,000	.3234	78,228	.1617
4,000	.0014	13,038	.0007	26,000	.3575	84,747	.1788
6,000	.0058	19,557	.0029	28,000	.4019	91,266	.2009
8,000	.0170	26,075	.0085	30,000	.4412	97,785	.2206
10,000	.0374	32,595	.0187	32,000	.4815	104,303	.2407
12,000	.0711	39,114	.0355	34,000	.5171	110,822	.2585
14,000	.1166	45,633	.0583	36,000	.5534	117,341	.2767
16,000	.1636	52,152	.0818	38,000	.5905	123,860	.2952
18,000	.2102	58,671	.1051	40,000	.6234	130,379	.3117
20,000	.2564	65,188	.1282	42,000	.6611	136,898	.3305
22,000	.2991	71,709	.1495	44,000	.6911	143,417	.3455

TABLE CCXX.—ALLOY OF COPPER AND TIN.

Original mark: No. 34.—Material: Alloy.—Original mixture: 82.5 Cu, 17.5 Sn.—Analysis: 82.72 Cu, 17.33 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	.....	.....	32,000	.2111	104,303	.1055
10,000	.0005	32,595	.00025	34,000	.2381	110,822	.1190
12,000	.0044	39,114	.0022	36,000	.2704	117,341	.1352
14,000	.0107	45,633	.0053	38,000	.3088	123,860	.1544
16,000	.0174	52,152	.0087	40,000	.3396	130,379	.1698
18,000	.0268	58,671	.0134	42,000	.3821	136,898	.1910
20,000	.0408	65,188	.0204	44,000	(*)	143,417	.....
22,000	.0628	71,709	.0314				
24,000	.0872	78,228	.0436				
26,000	.1123	84,747	.0561				
28,000	.1464	91,266	.0732				
30,000	.1766	97,785	.0883				

* A wedge-shaped piece slid off at the top, and a piece cracked off at the bottom; it was also cracked badly at the middle.

TABLE CCXXI.—ALLOY OF COPPER AND TIN.

Original mark: No. 35.—Material: Alloy.—Original mixture: 77.5 Cu, 22.5 Sn.—Analysis: 77.56 Cu, 22.25 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

150	.0000	.....	.....	34,000	.0447	110,822	.0221
14,000	.0009	45,633	.00045	36,000	.0614	117,341	.0307
16,000	.0029	52,152	.00145	38,000	.0807	123,860	.0403
18,000	.0045	58,671	.00225	40,000	.1006	130,379	.0503
20,000	.0070	65,188	.0035	42,000	.1212	136,898	.0606
22,000	.0092	71,709	.0046	44,000	.1537	143,417	.0768
24,000	.0120	78,228	.0060	46,000	.2027	149,936	.1013
26,000	.0155	84,747	.0077				
28,000	.0190	91,266	.0095				
30,000	.0260	97,785	.0130				
32,000	.0342	104,303	.0171				

The specimen was cracked a little at the top. Had to stop on account of the capacity of the machine.

TABLE CXXII.—ALLOY OF COPPER AND TIN.

Original mark: No. 43.—Material: Alloy.—Original mixture: 37.5 Cu, 62.5 Sn.—Analysis: 37.10 Cu, 62.9 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.
Pounds.	*Inches.*	*Pounds.*	
150	.0000	.....	.....
2,000	.0051	6,519	.0025
4,000	(*)	.....	.....

* The bottom of the specimen all crumbled away.

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

HANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXXIII.—ALLOY OF COPPER AND TIN.

l mark: No. 44.—Material: Alloy.—Original mixture: 32.5 Cu, 62.5 Sn.—Analysis: 30.76 Cu, 69.19 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Compression.	Load per square inch.	Compression in parts of original length.	
Inches.	*Pounds.*		
.0000	.....	.....	Broke by a wedge-shaped piece sliding off of the top; the bottom cracked.
.0010	9,778	.0005	
.0081	13,038	.0040	
Lifted the beam.	16,297	.....	

TABLE CCXXIV.—ALLOY OF COPPER AND TIN.

l mark: No. 45.—Material: Alloy.—Original mixture: 27.5 Cu, 72.5 Sn.—Analysis: 26.62 Cu, 73.18 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

.0000	.....	.....	Crushed by having a wedge-shaped piece slide out of the middle of the specimen.
.0019	6,519	.00095	
.0062	9,778	.0031	
.0182	13,038	.0091	
Lifted the beam.	16,297	.....	

TABLE CCXXV.—ALLOY OF COPPER AND TIN.

l mark: No. 46.—Material: Alloy.—Original mixture: 22.5 Cu, 77.5 Sn.—Analysis: 22.10 Cu, 77.56 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

.0000	.....	.....	Broke by wedge-shaped piece sliding off the specimen near the bottom.
.0028	3,259	.0014	
.0057	6,519	.0028	
.0103	9,778	.0051	
.0227	13,038	.0113	
Lifted the beam.	16,297	.....	

TABLE CCXXVI.—ALLOY OF COPPER AND TIN.

l mark: No. 47.—Material: Alloy.—Original mixture: 17.5 Cu, 82.5 Sn.—Analysis: 16.70 Cu, 83.23 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

.0000	.....	.....	The specimen crushed by having a wedge-shaped piece slide out at the middle.
.0006	3,259	.0003	
.0051	6,519	.0025	
Lifted the beam.	9,778	.....	

RECORD OF TESTS BY COMPRESSIVE STRESS—Continued.

MECHANICAL LABORATORY, DEPARTMENT OF ENGINEERING, STEVENS INSTITUTE OF TECHNOLOGY.

TABLE CCXXVII.—ALLOY OF COPPER AND TIN.

Original mark: No. 48.—Material: Alloy.—Original mixture: 12.5 Cu, 87.5 Sn.—Analysis: 11.68 88.25 Sn.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	The specimen was broken by having a wed shaped piece slide off at the top and at the bott
Pounds.	*Inches.*	*Pounds.*		
150	.0000	.....	.....	
1,000	.0009	3,259	.00045	
2,000	.0176	6,519	.0088	
3,000	.0611	9,778	.0305	
4,000	Lifted the beam.	.....	.....	

TABLE CCXXVIII.—CAST COPPER.

Original mark: No. 51 B.—Material: Cast copper.—Dimensions: Length, 2″. Diameter, 0.625″.

Load.	Compression.	Load per square inch.	Compression in parts of original length.	Load.	Compression.	Load per square inch.	Compression in parts of origi nal length.
Pounds.	*Inches.*	*Pounds.*		*Pounds.*	*Inches.*	*Pounds.*	
150	.0000	.....	.....	20,000	.6461	65,188	.3230
4,000	.0006	13,038	.0003	22,000	.7295	71,709	.3647
6,000	.0089	19,557	.0044	24,000	.7936	78,228	.3968
8,000	.0573	26,075	.0286	26,000	.8619	84,747	.4309
10,000	.1560	32,595	.0780	28,000	.9258	91,266	.4679
12,000	.2568	39,114	.1284	30,000	.9783	97,785	.4891
14,000	.3602	45,633	.1801	32,000	1.0308	104,303	.5154
16,000	.4489	52,152	.2244	Specimen did not show any cracks, but merely
18,000	.5511	58,671	.2756	flattened down.

TABLE CCXXIX.—CAST COPPER.

Original mark: No. 52.—Material: Cast copper.—Dimensions: Length, 2″. Diameter, 0.625″.

150	0.0000	.....	.....	18,000	.5770	58,671	.2885
6,000	.0041	19,557	.0020	20,000	.6815	65,188	.3408
8,000	.0305	26,075	.0153	22,000	.7665	71,709	.3833
10,000	.1372	32,595	.0686	24,000	.7925	78,228	.3962
12,000	.2375	39,114	.1186	26,000	.9025	84,747	.4512
14,000	.3547	45,633	.1773	28,000	.9628	91,266	.4814
16,000	.4737	52,152	.2368				

TABLE CCXXX.—CAST COPPER.

Original mark: No. 53.—Material: Cast copper.—Dimensions: Length, 2″. Diameter, 0.625″.—

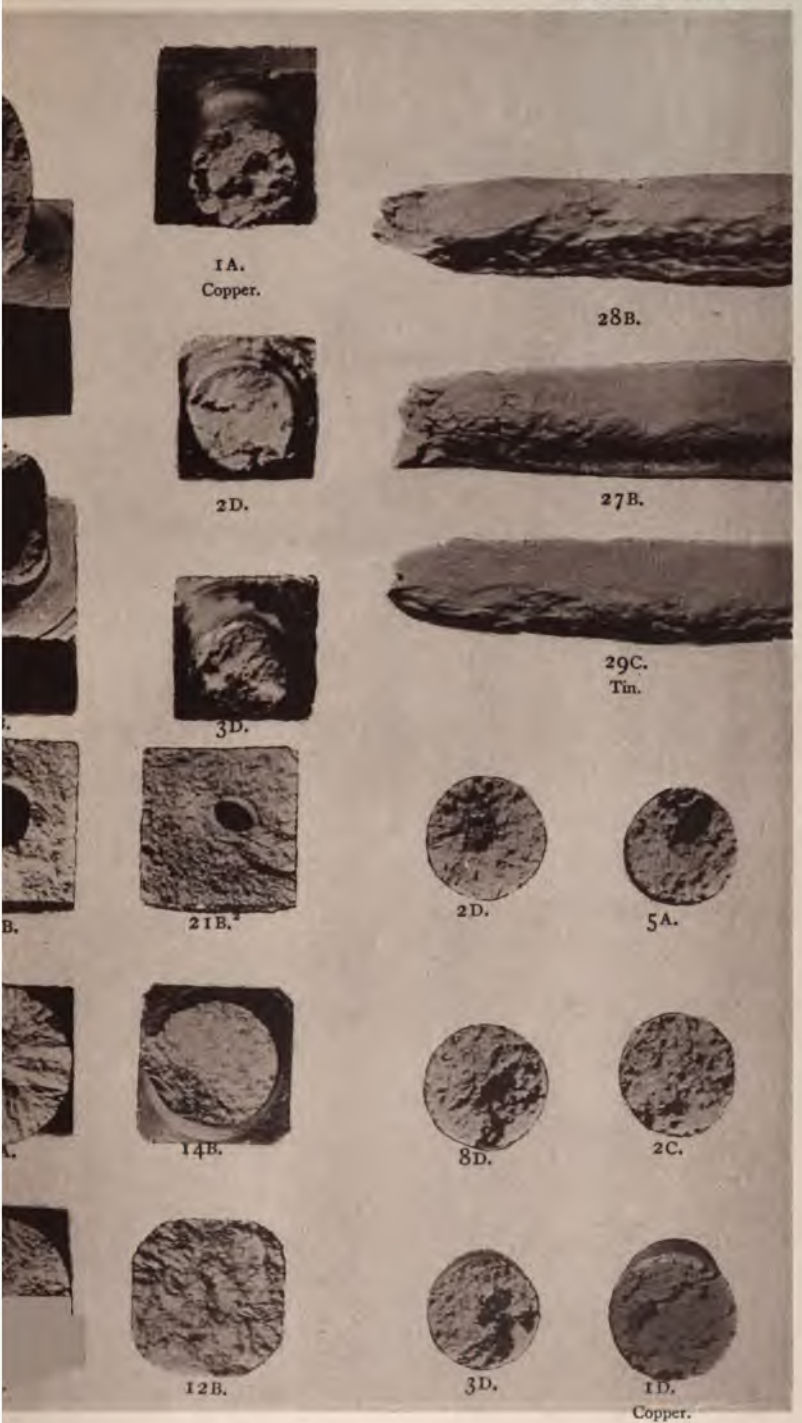
150	.0000	.....	.....	18,000	.3194	58,671	.1597
4,000	.0060	13,038	.0030	20,000	.4029	65,188	.2014
6,000	.0148	19,557	.0074	22,000	.4991	71,709	.2495
8,000	.0485	26,075	.0242	24,000	.5893	78,228	.2946
10,000	.0851	32,595	.0425	26,000	.6853	84,747	.3426
12,000	.1285	39,114	.0642	28,000	.7542	91,266	.3871
14,000	.1777	45,633	.0888	30,000	.8244	97,785	.4122
16,000	.2411	52,152	.1205	Flattened down without showing any cra

PHOTOGRAPHS OF FRACTURES

OF

COPPER-TIN ALLOYS.

PLATE No. 1.


1A.
Copper.
28B.
2D.
27B.
29C.
Tin.
3D.
21B.
2D.
5A.
14B.
8D.
2C.
12B.
3D.
1D.
Copper.

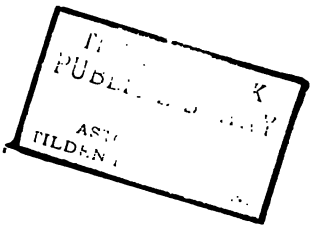
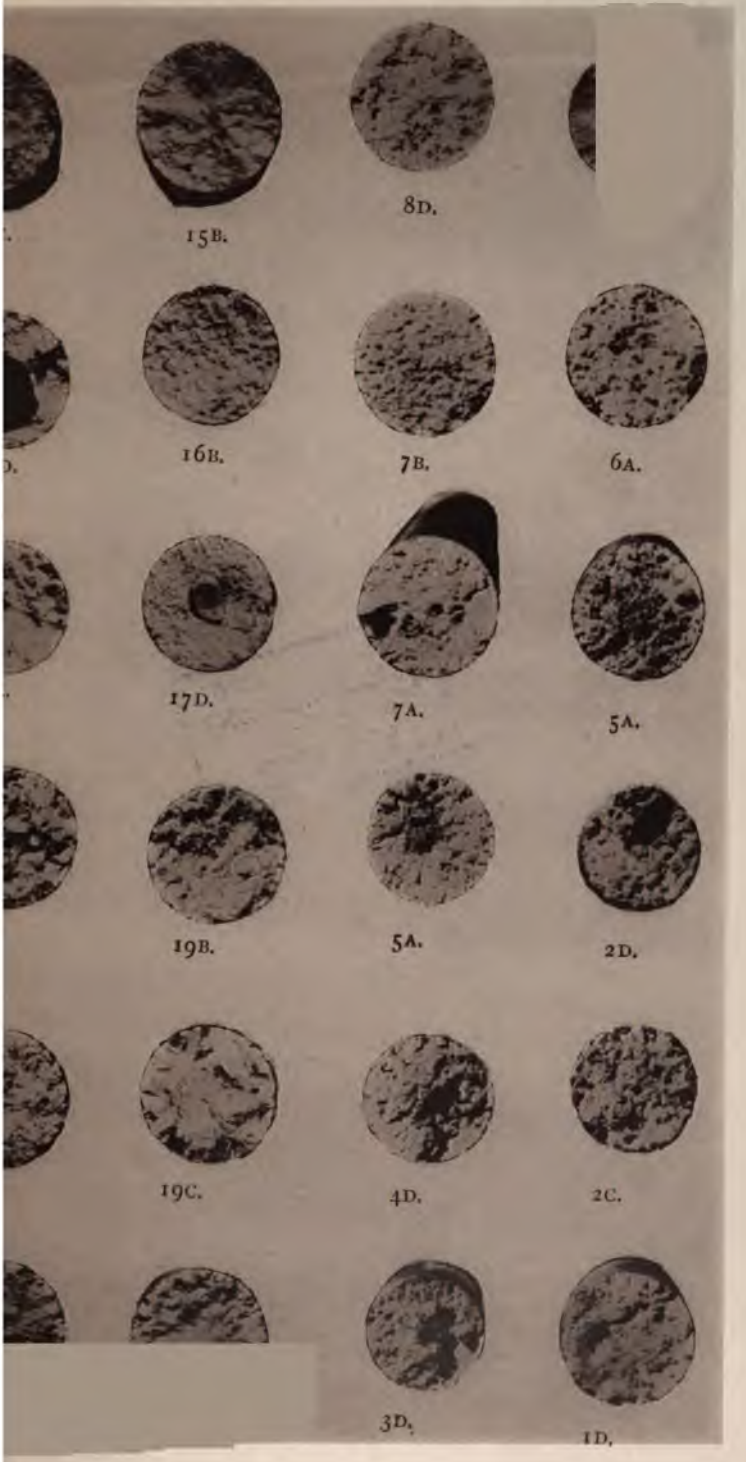
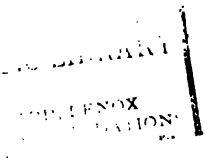

PUBLIC
ASTOR
TILDEN

PLATE No. 2.





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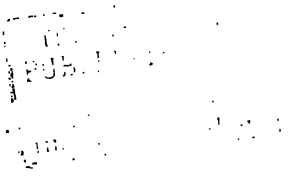

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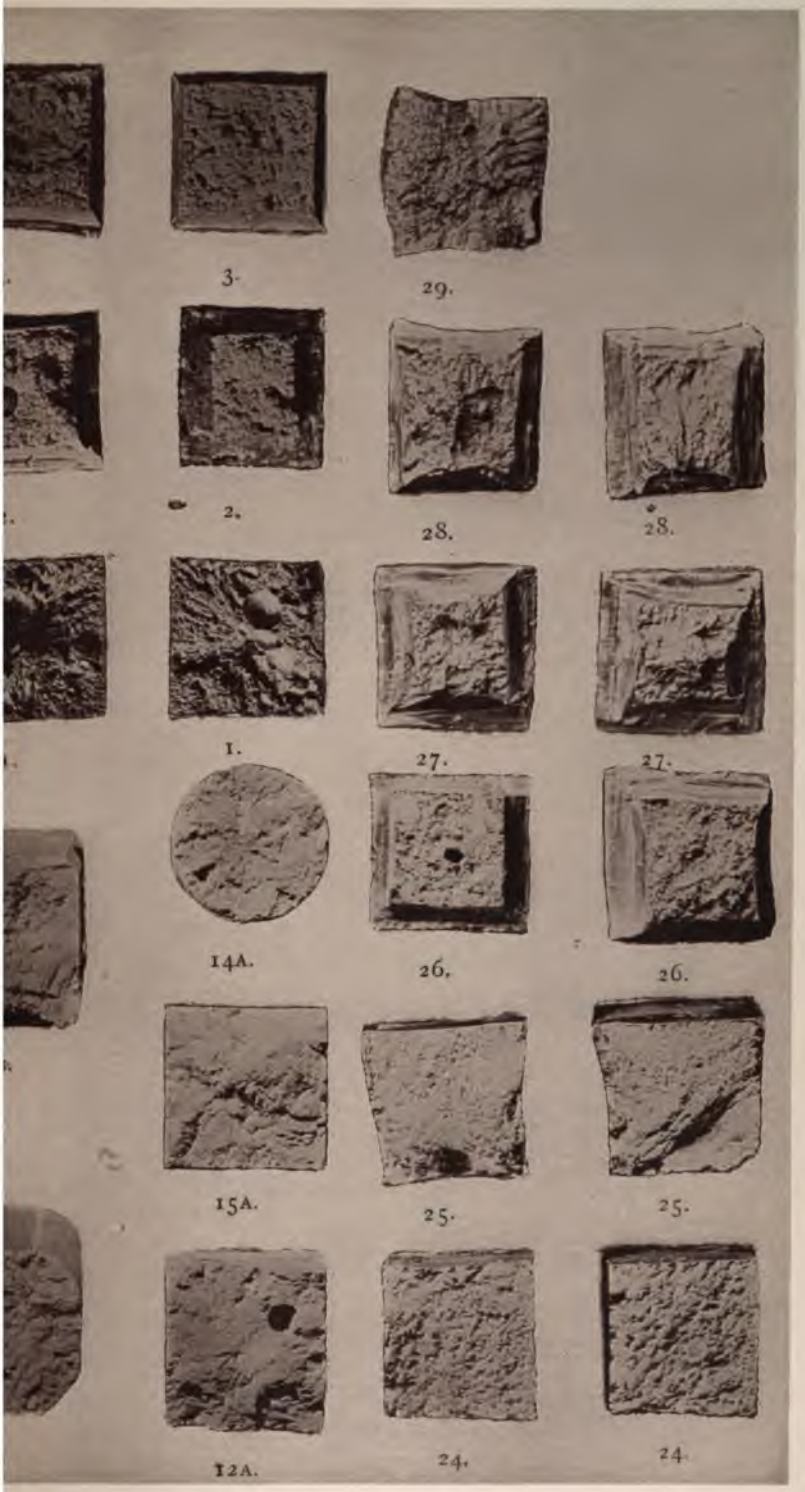

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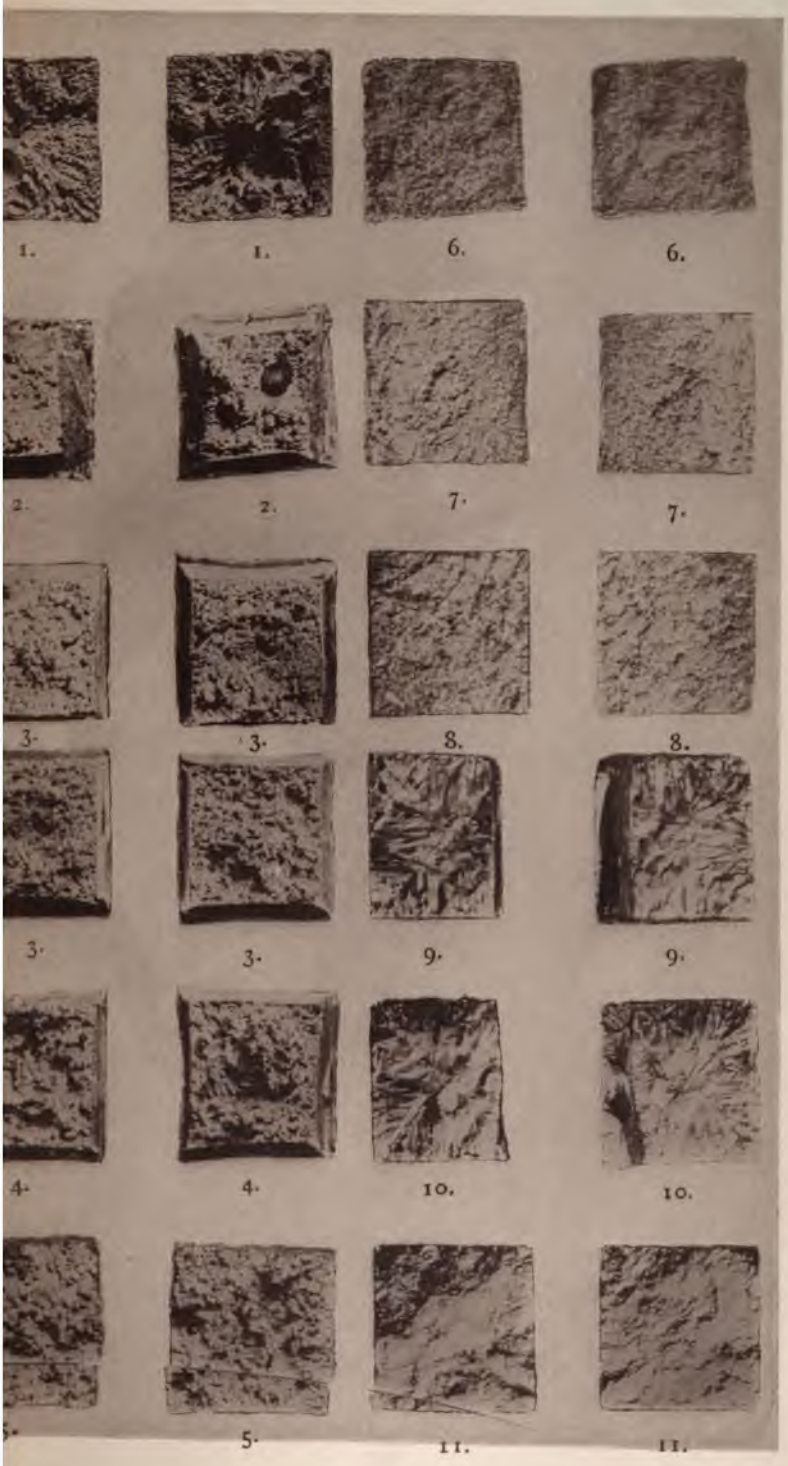

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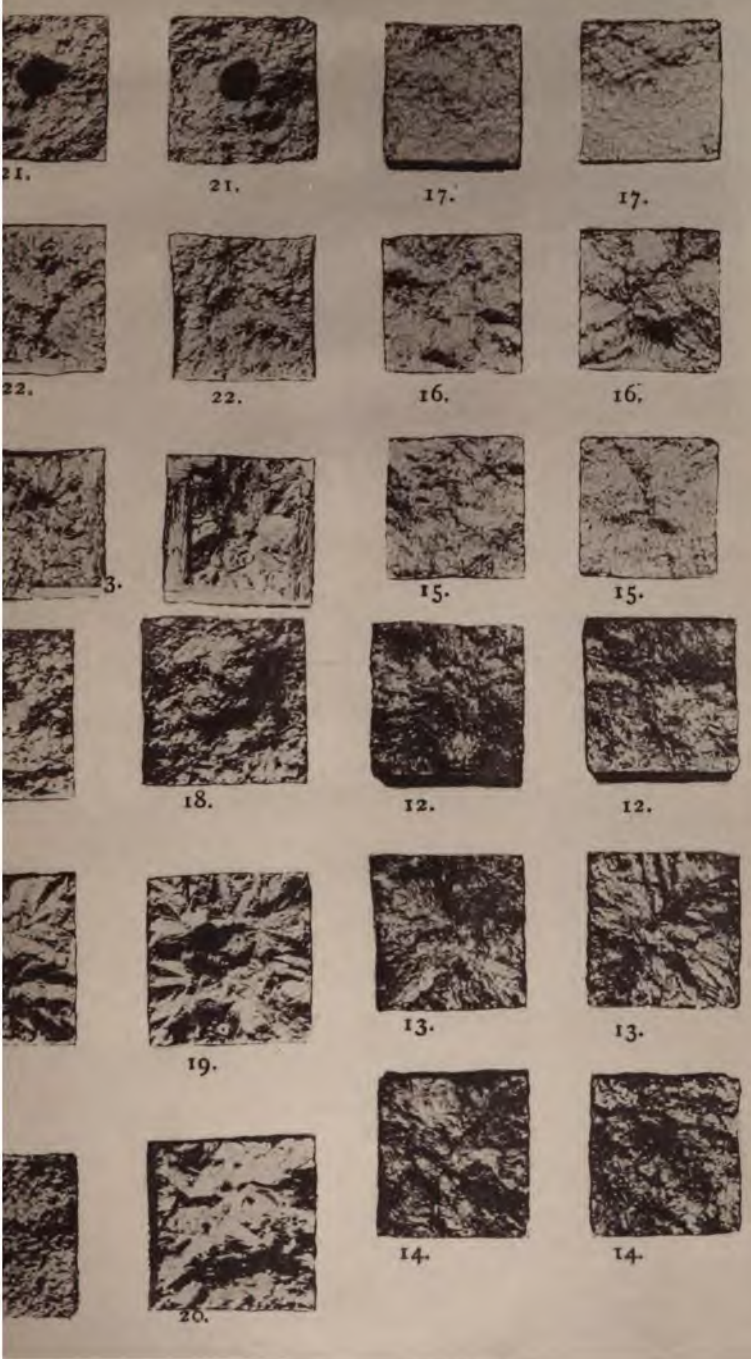


PLATES I–XXI.

GRAPHICAL REPRESENTATIONS

OF THE

PROPERTIES OF COPPER-TIN ALLOYS.

PLATE I.—Tests by Transverse Stress.
Modulus of Rupture in Pounds.
Modulus at Elastic Limit in Pounds.
Total Deflection in Inches.
PLATE II.—Tests by Tensile Stress.
Tensile Strength in Pounds per Square Inch of Original Section.
Tensile Strength in Pounds per Square Inch of Fractured Section.
Tensile Strength at the Elastic Limit.
Total Elongation in Parts of Original Length.
PLATE III.—Tests by Torsional Stress.
Maximum Torsional Moment in Foot-Pounds.
Torsional Moment at Elastic Limit in Foot-Pounds.
Resilience in Foot-Pounds.
Extension of Exterior Fiber in Parts of Original Length.
PLATE IV.—Tests by Compressive Stress.
Crushing Strength in Pounds per Square Inch.
Total Compression at Maximum Load in Parts of Original Length.
PLATE V.—Mean Specific Gravity.
PLATE VI.—Variation of Analyses from Original Compositions.
PLATE VII.—Comparison of Transverse, Tensile, Torsional, and Compressive Resistan
Transverse Modulus of Rupture in Pounds.
Tensile Strength in Pounds per Square Inch of Original Section.
Crushing Strength in Pounds per Square Inch.
Maximum Torsional Moment in Foot-Pounds.
PLATE VIII.—Comparison of Transverse, Tensile, and Torsional Resistances [Scale Enl
Transverse Modulus of Rupture in Pounds.
Tensile Strength per Square Inch of Original Section.
Maximum Torsional Moment in Foot-Pounds.
PLATE IX.—Ductility as Shown by Transverse, Tensile, and Torsion Tests.
Total Transverse Deflection in Inches.
Tensile Elongation in Parts of Original Length.
Torsional Elongation of Exterior Fibers in Parts of Original Length.
PLATE X.—Resilience under Transverse and Torsional Stresses.
PLATE XI.—Moduli of Elasticity from Transverse Tests.
PLATE XII.—Specific Gravity—Authorities Compared.
Authorities: United States Board, Riche, Mallet, Calvert and Johnson.
PLATE XIII.—Tenacity—Authorities Compared.
Authorities: United States Board, Mallet.
PLATE XIV.—Heat and Electric Conductivity.
Heat Conductivity—Calvert and Johnson.
Electric Conductivity—Matthiessen.
PLATE XV.—Hardness, Malleability, Ductility, Fusibility.
Order of Hardness—Mallet, Calvert and Johnson.
Order of Malleability—Mallet.
Order of Ductility—Mallet.
Order of Fusibility—Mallet.

RECORDS OF INDIVIDUAL TESTS.

PLATE XVI.—Deflections by Transverse Stresses. First Series of Tests.
PLATE XVII.—Deflections by Transverse Stresses. Second Series of Tests.
PLATE XVIII.—Elongations by Tensile Stresses. First Series of Tests.
PLATE XIX.—Elongations by Tensile Stresses. Second Series of Tests.
PLATE XX.—Compressions by Compressive Stresses. First Series of Tests.
PLATE XXI.—Compressions by Compressive Stresses. Second Series of Tests.

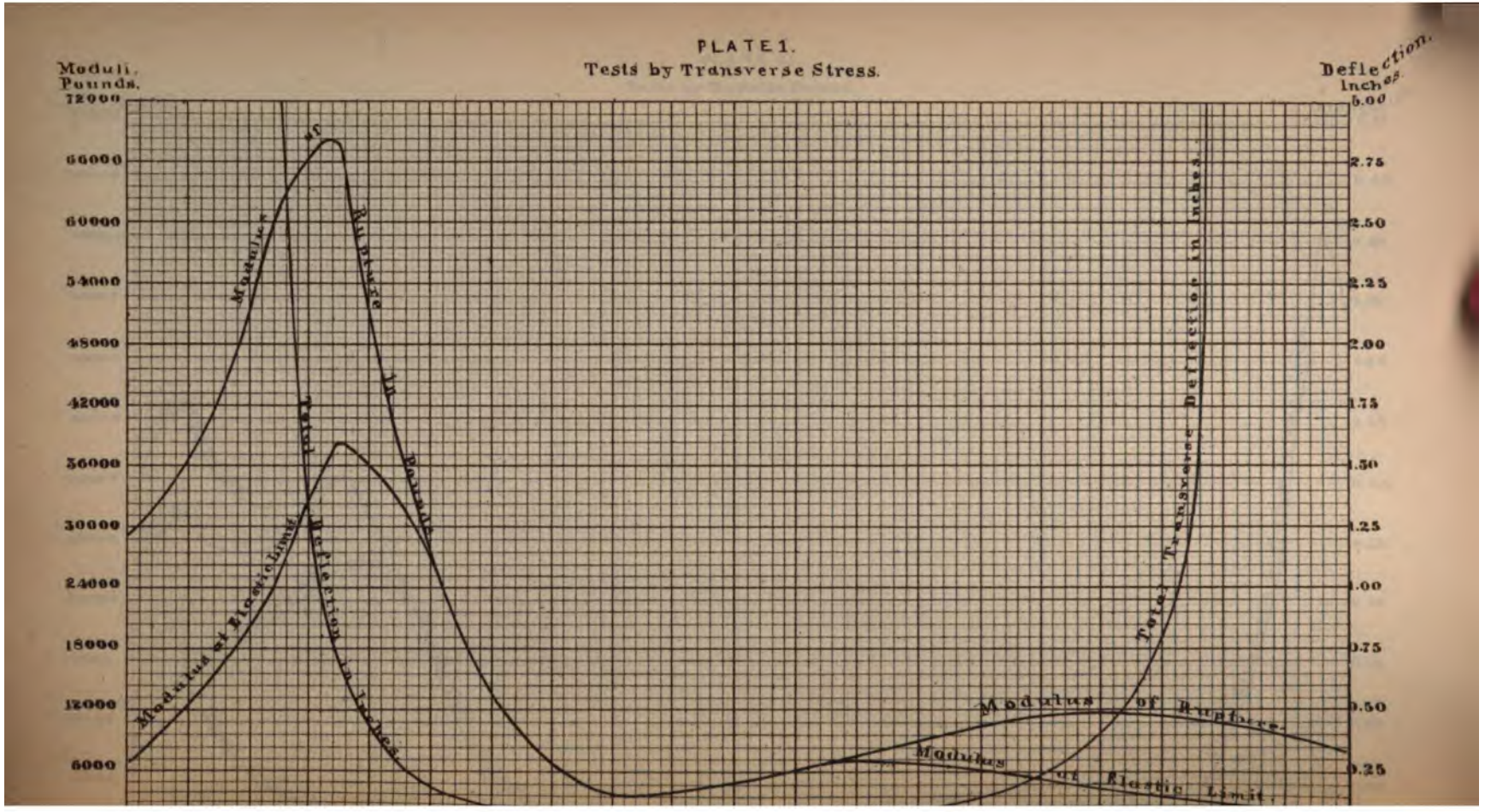
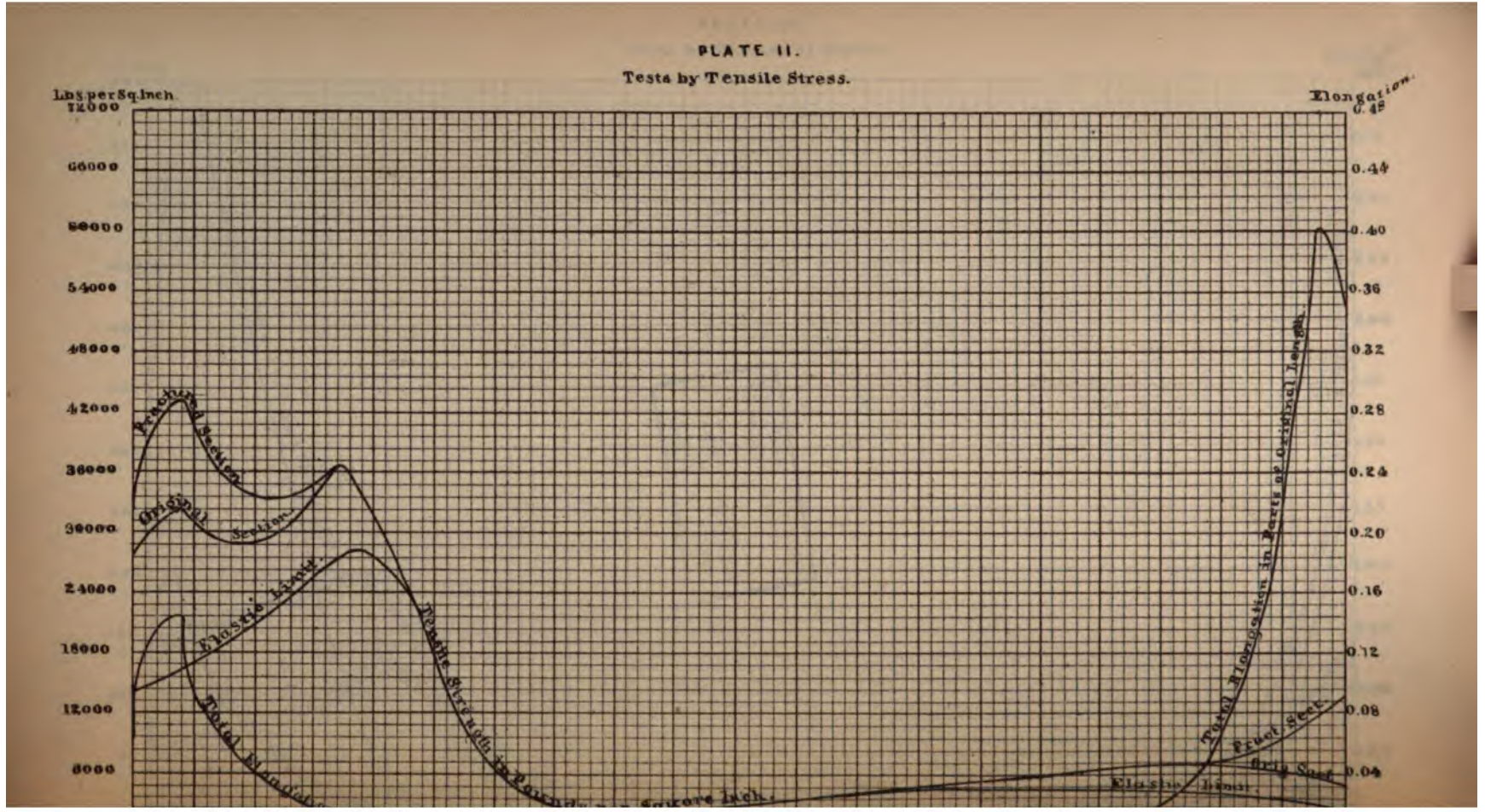


PLATE 1.
Tests by Transverse Stress.
Moduli, Pounds.
Deflection, Inches.
72000
66000
60000
54000
48000
42000
36000
30000
24000
18000
12000
6000
5.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
Modulus of Rupture.
Modulus of Elastic Limit.
Total Deflection in Inches.
Total Transverse Deflection in Inches.

PLATE II.

Tests by Tensile Stress.



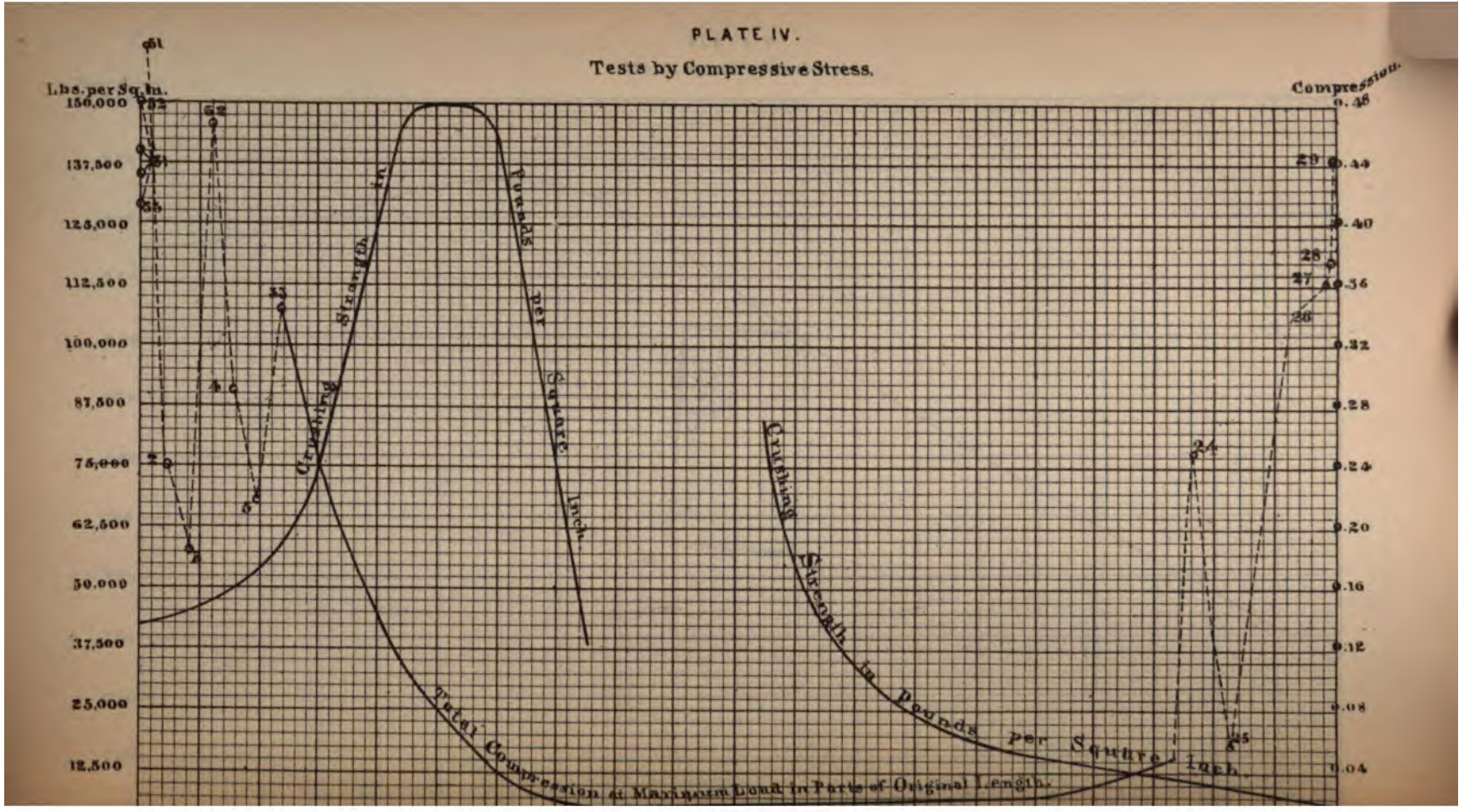
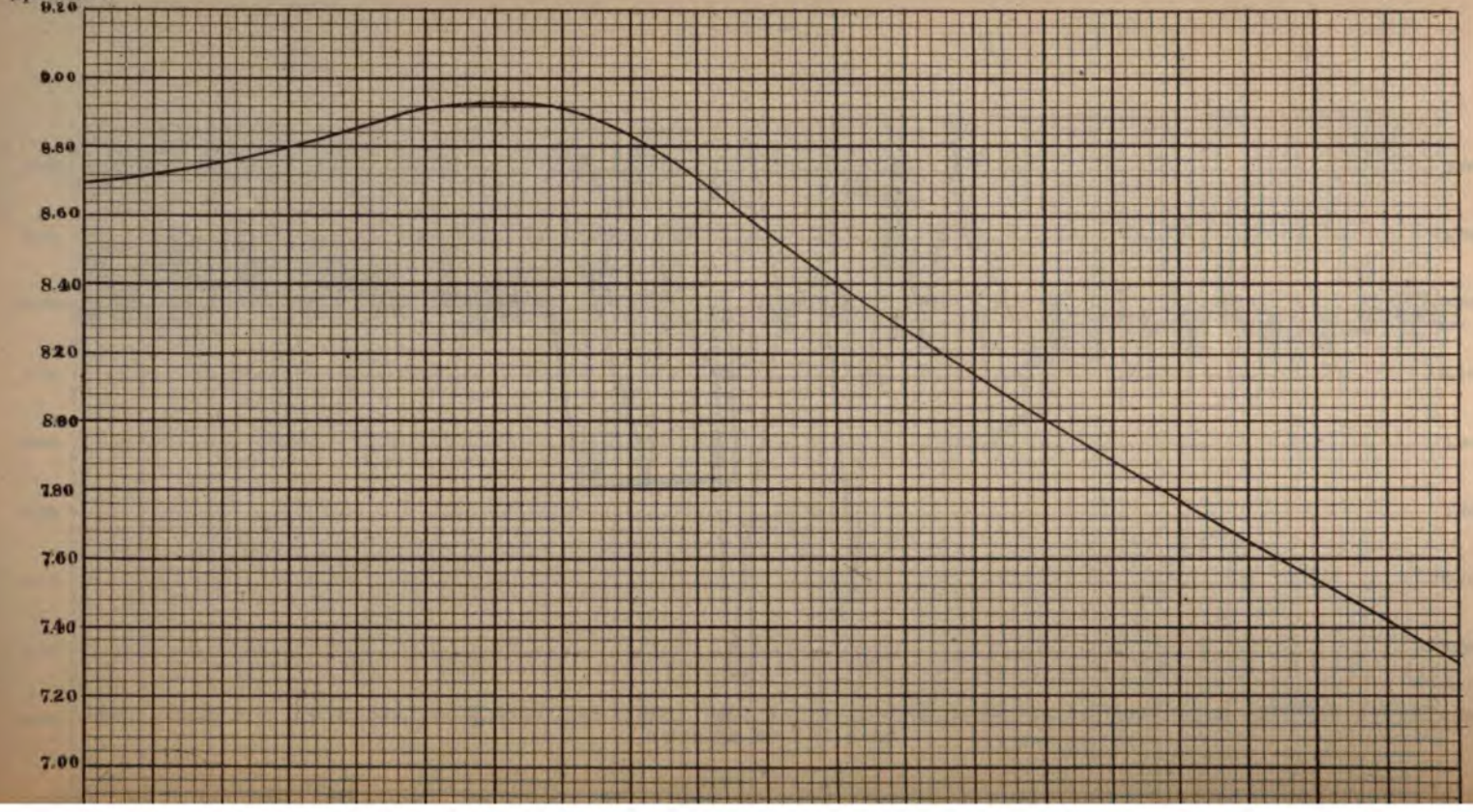


PLATE IV.
Tests by Compressive Stress.
Lbs. per Sq. In.
150,000
137,500
125,000
112,500
100,000
87,500
75,000
62,500
50,000
37,500
25,000
12,500
Compression.
0.48
0.44
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
Crushing Strength in Pounds per Square Inch.
Total Compression at Maximum Load in Parts of Original Length.

PLATE V.

Mean Specific Gravity.



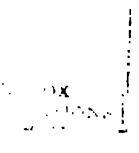
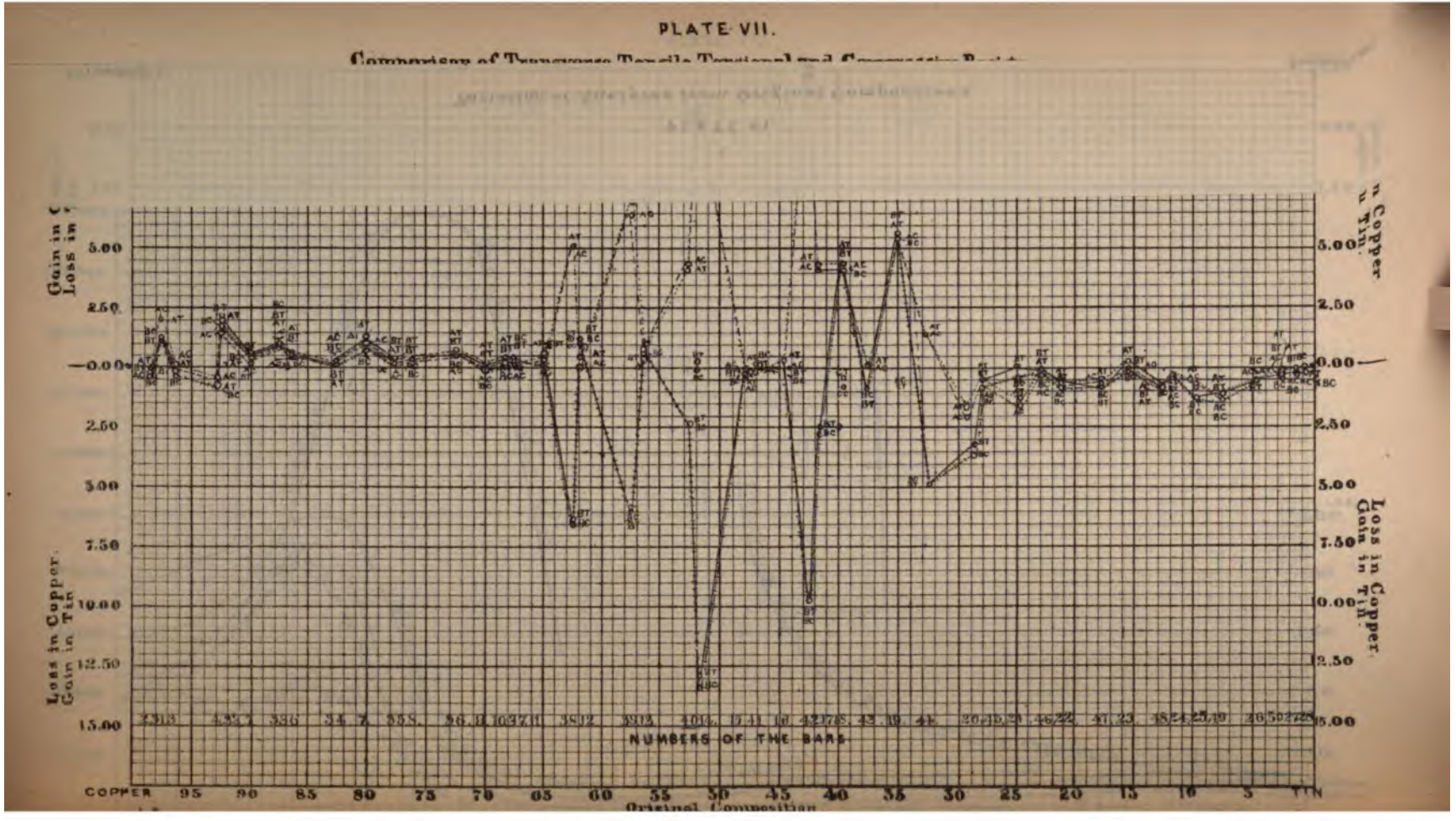


PLATE VII.

Comparison of Transverse Tensile Torsional and Compressive Resistance



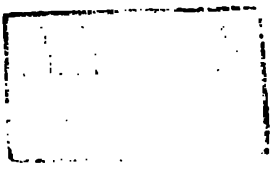
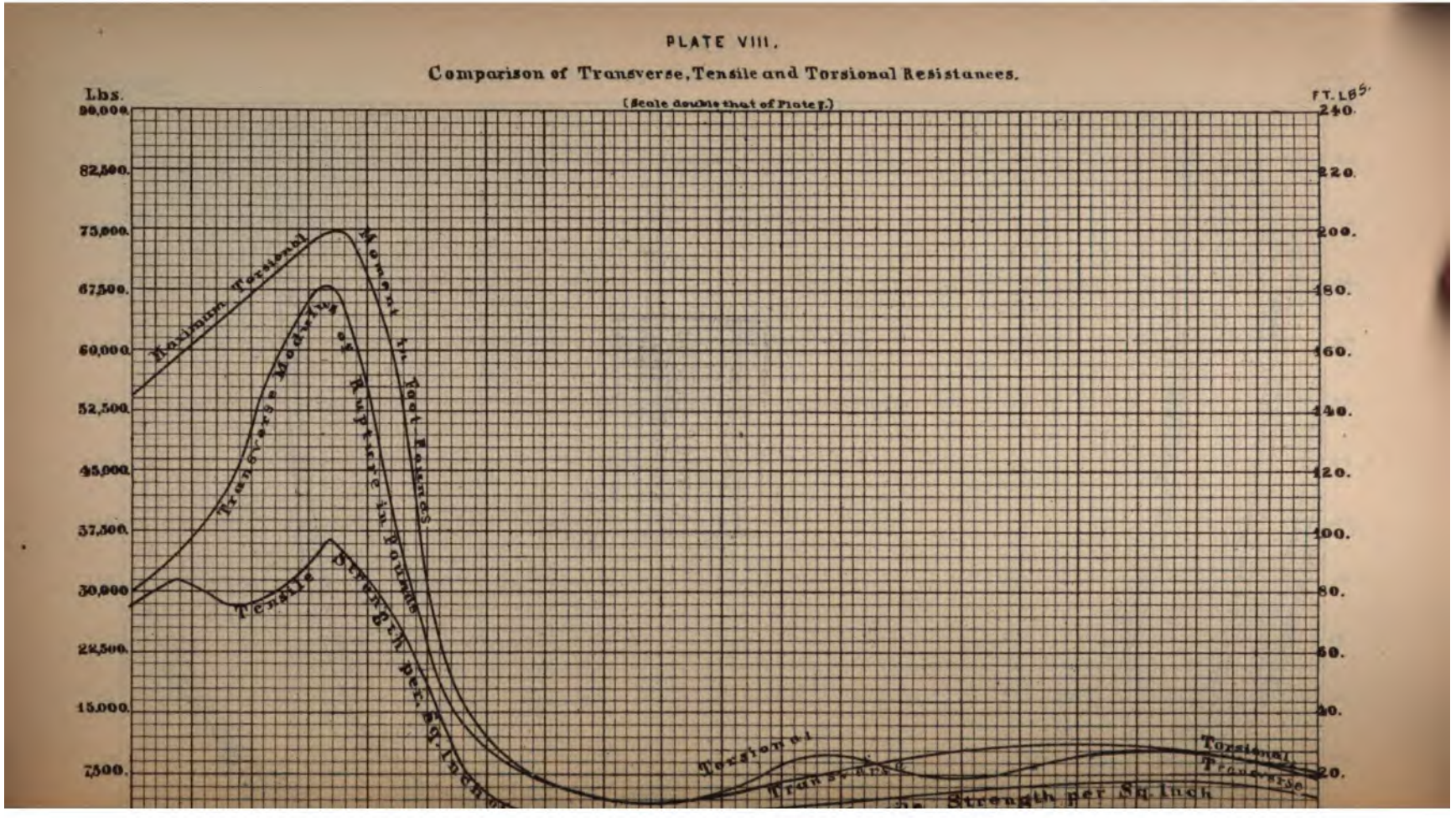


PLATE VIII.

Comparison of Transverse, Tensile and Torsional Resistances.



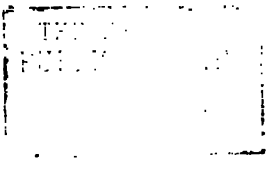


PLATE IX.

Ductility as shown by Transverse, Tensile and Torsion Tests.

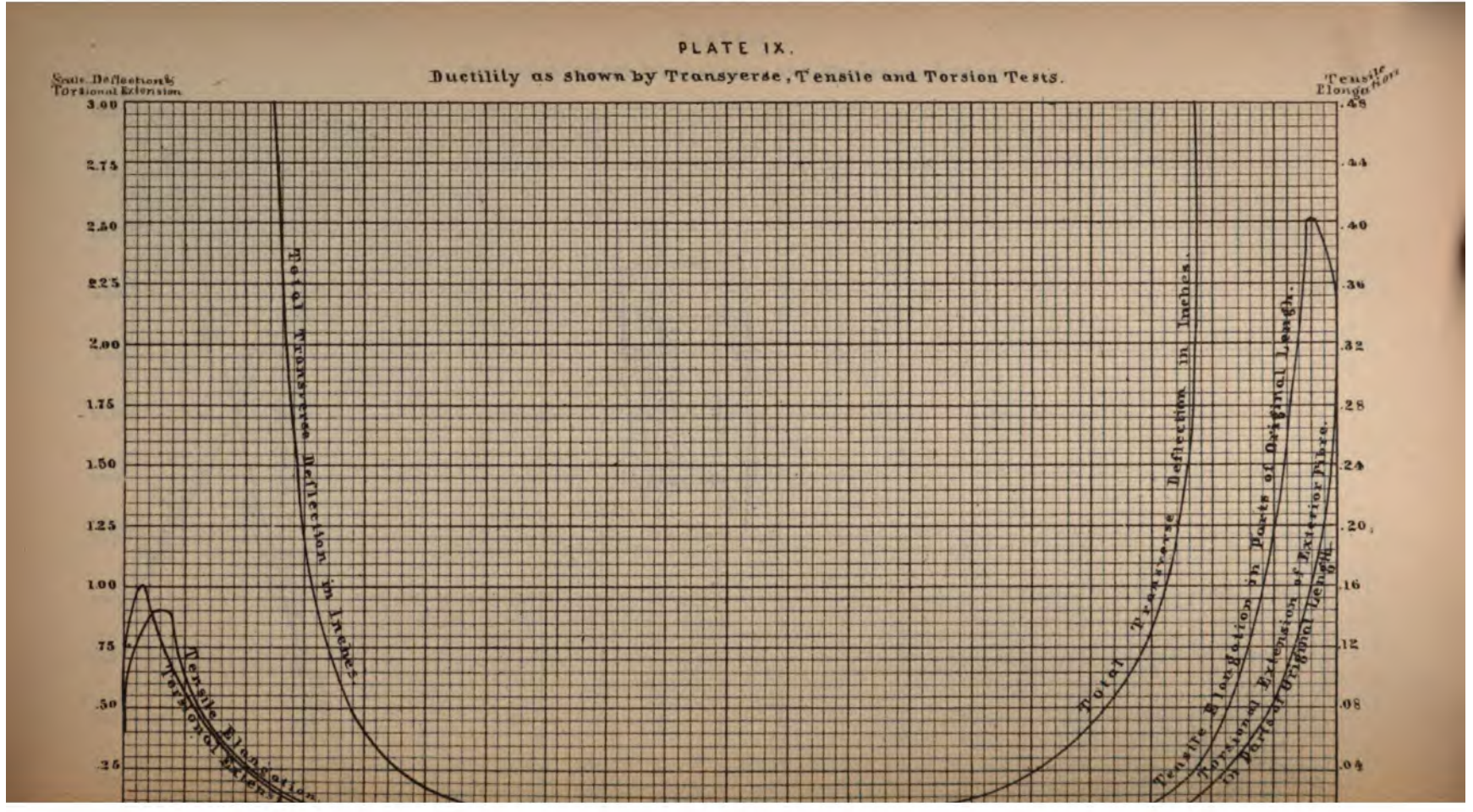
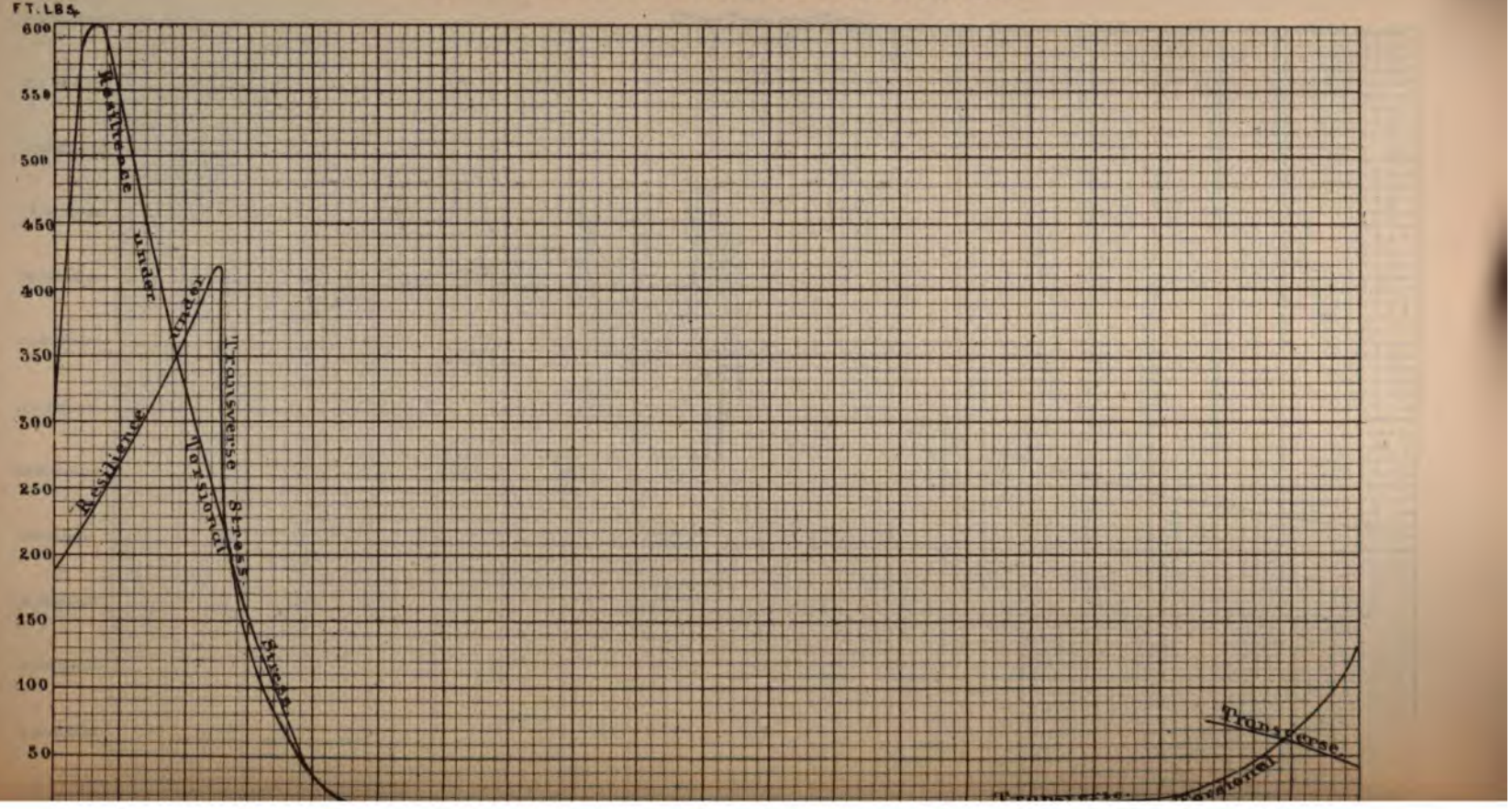


PLATE X.

Resilience under Transverse and Torsional Stresses.



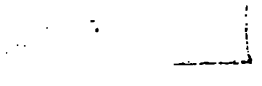


PLATE XI.

Moduli of Elasticity.

[From Transverse Tests]

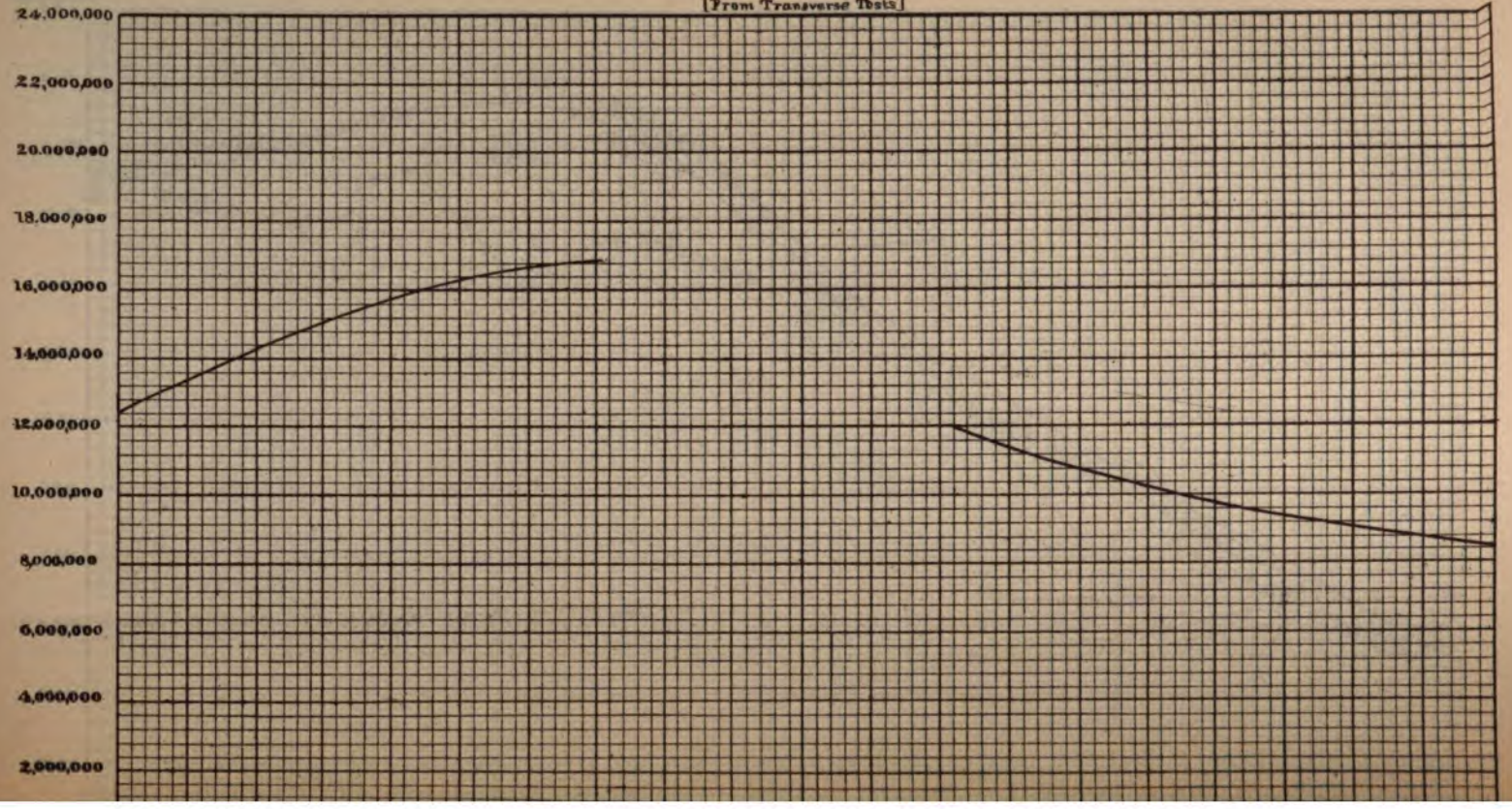
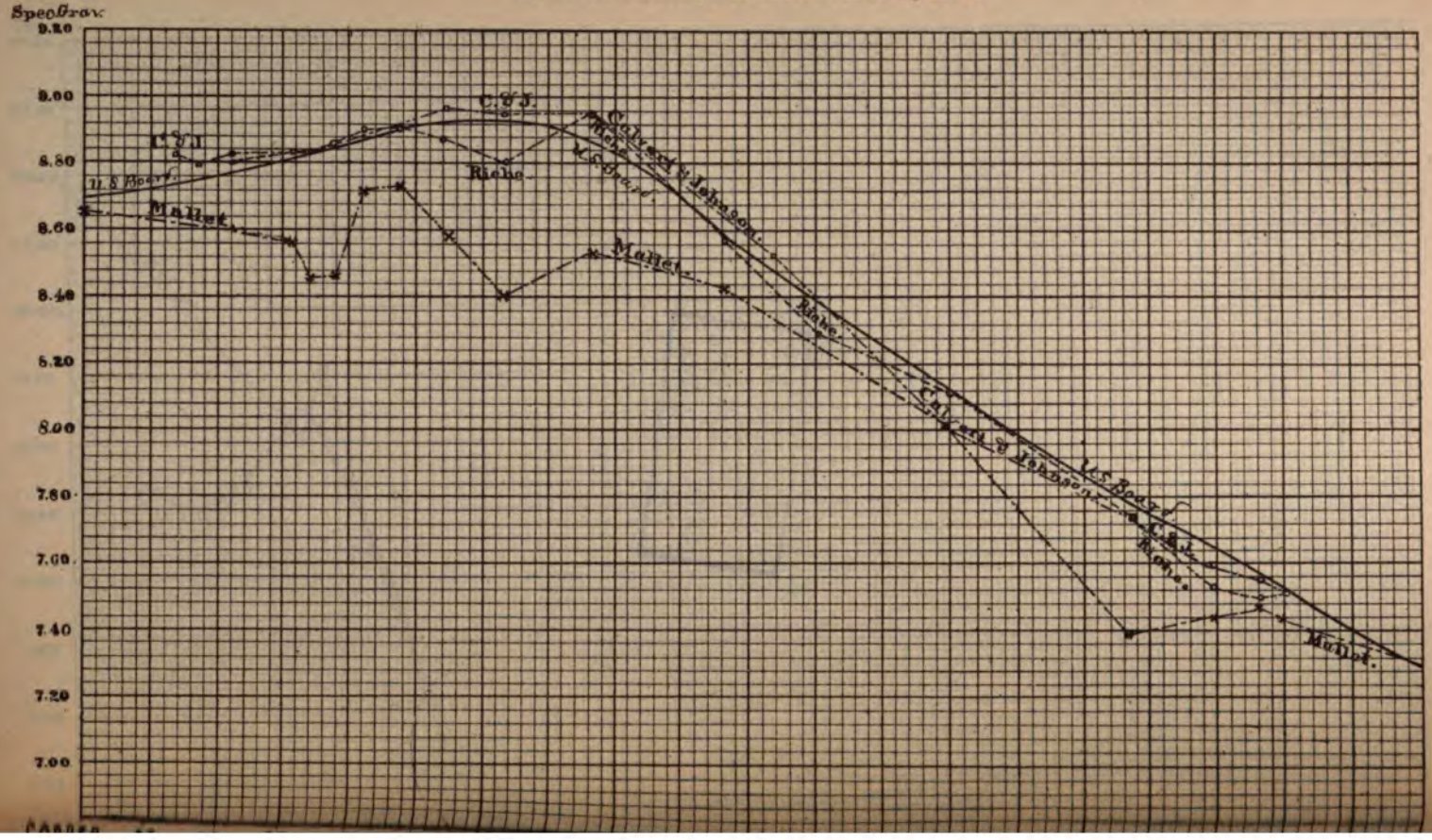


PLATE XII

Specific Gravity. Authorities compared.



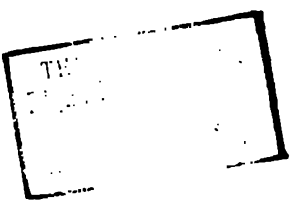
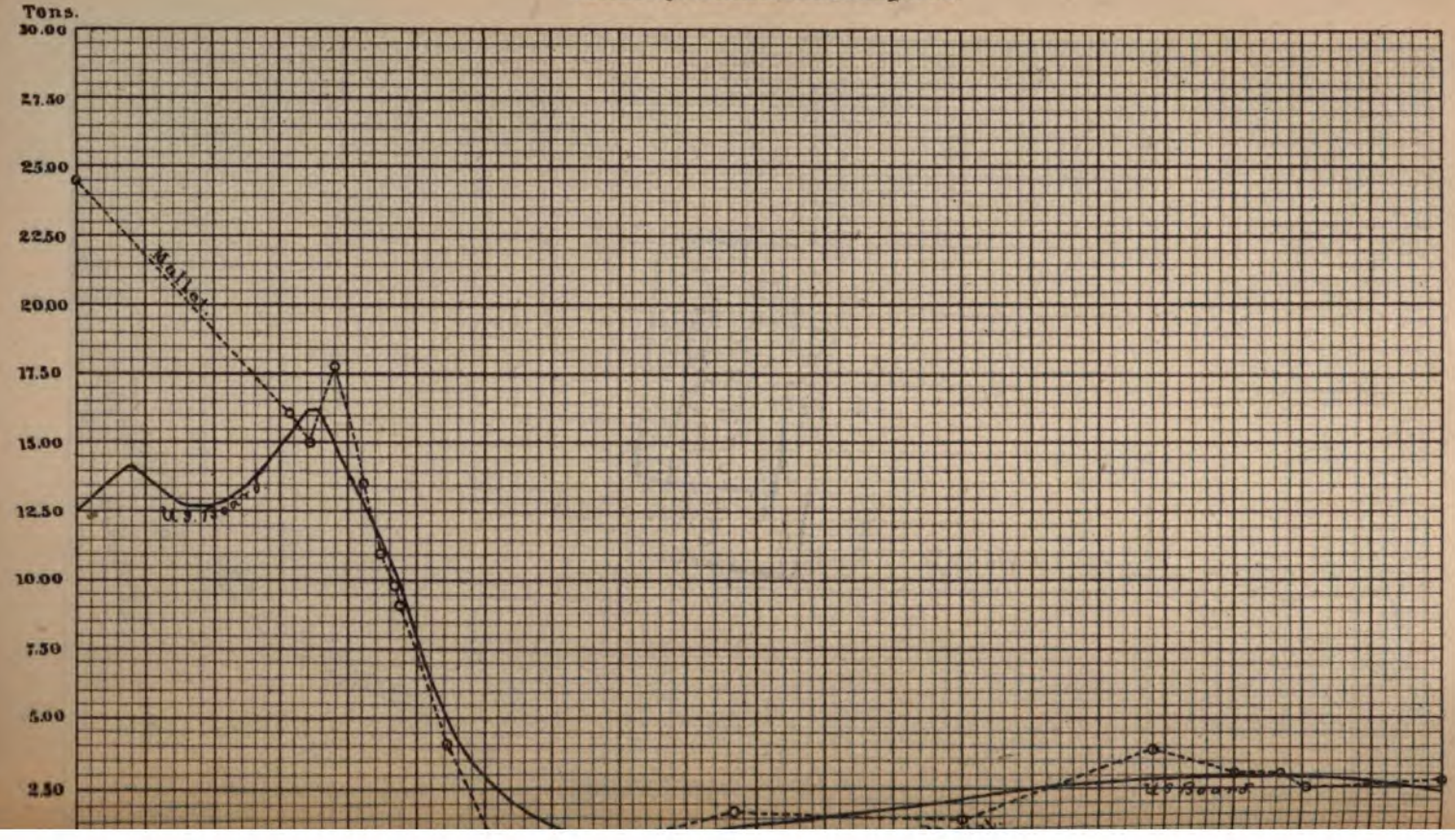


PLATE XIII:

Tenacity. Authorities compared.



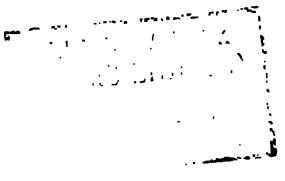


PLATE XIV.

Heat and Electric Conductivity

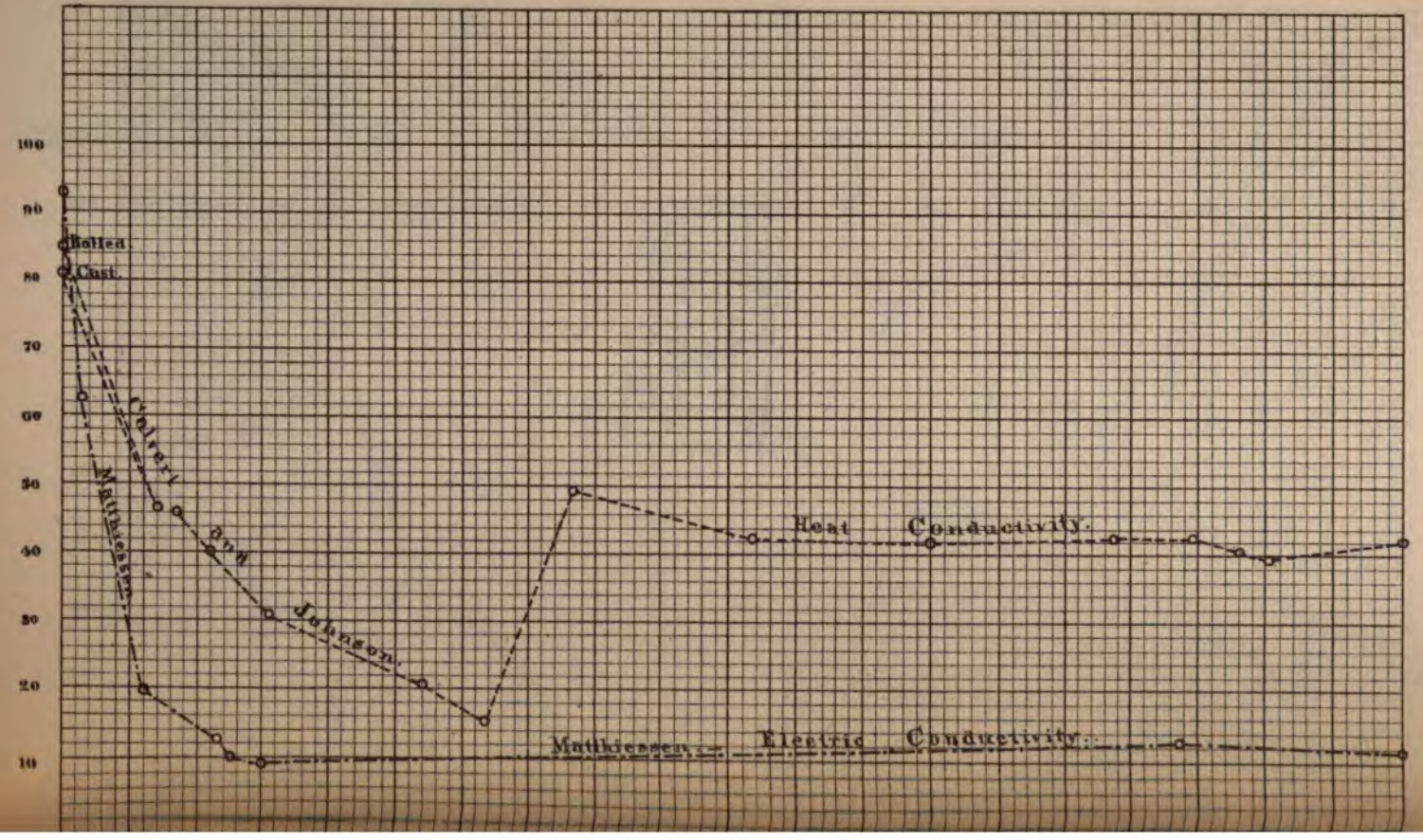


PLATE XV.

Hardness.—Malleability.—Ductility.—Fusibility.

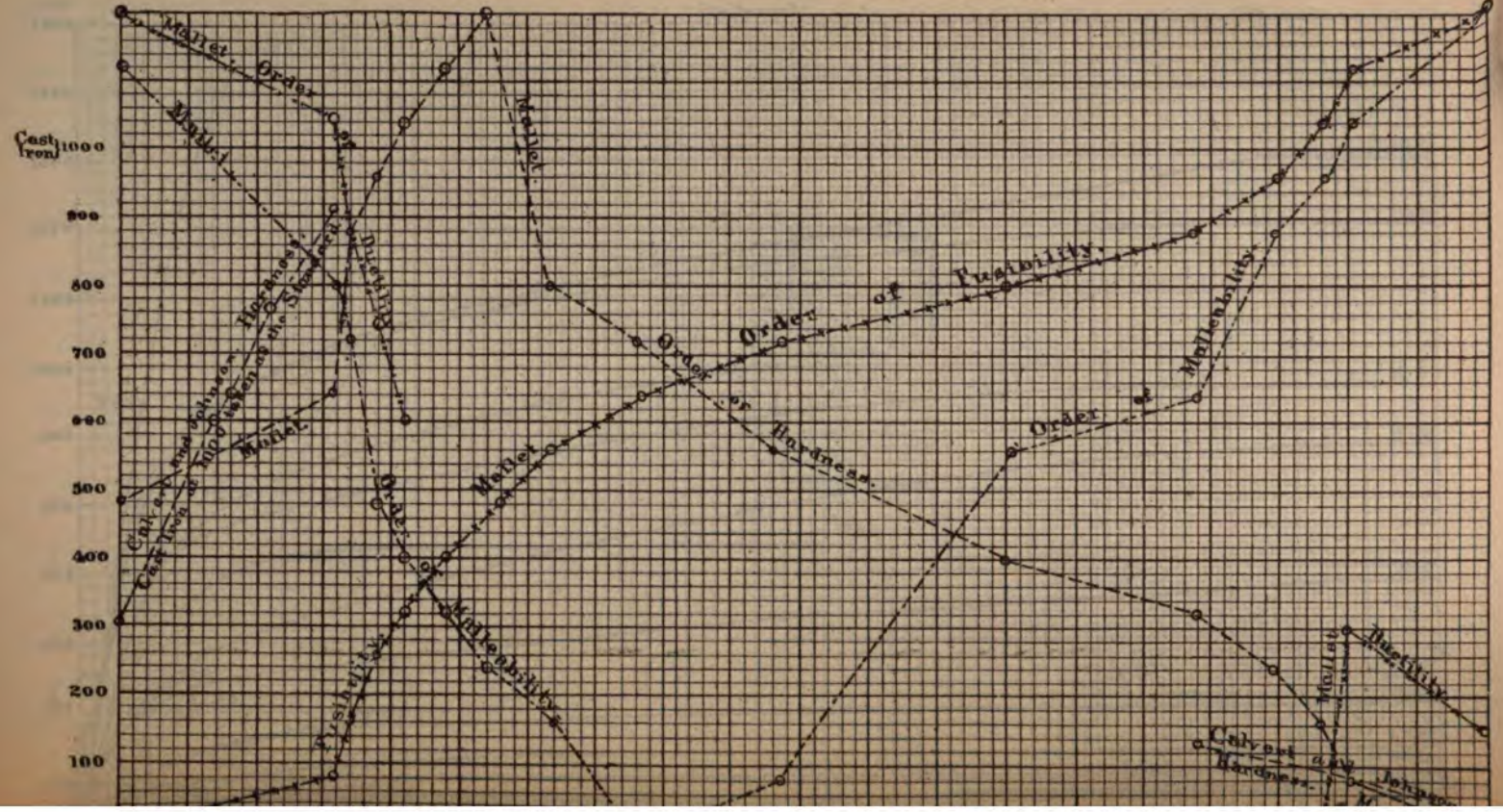


PLATE XVI

Tests by Transverse Stress.

[1st. Series]

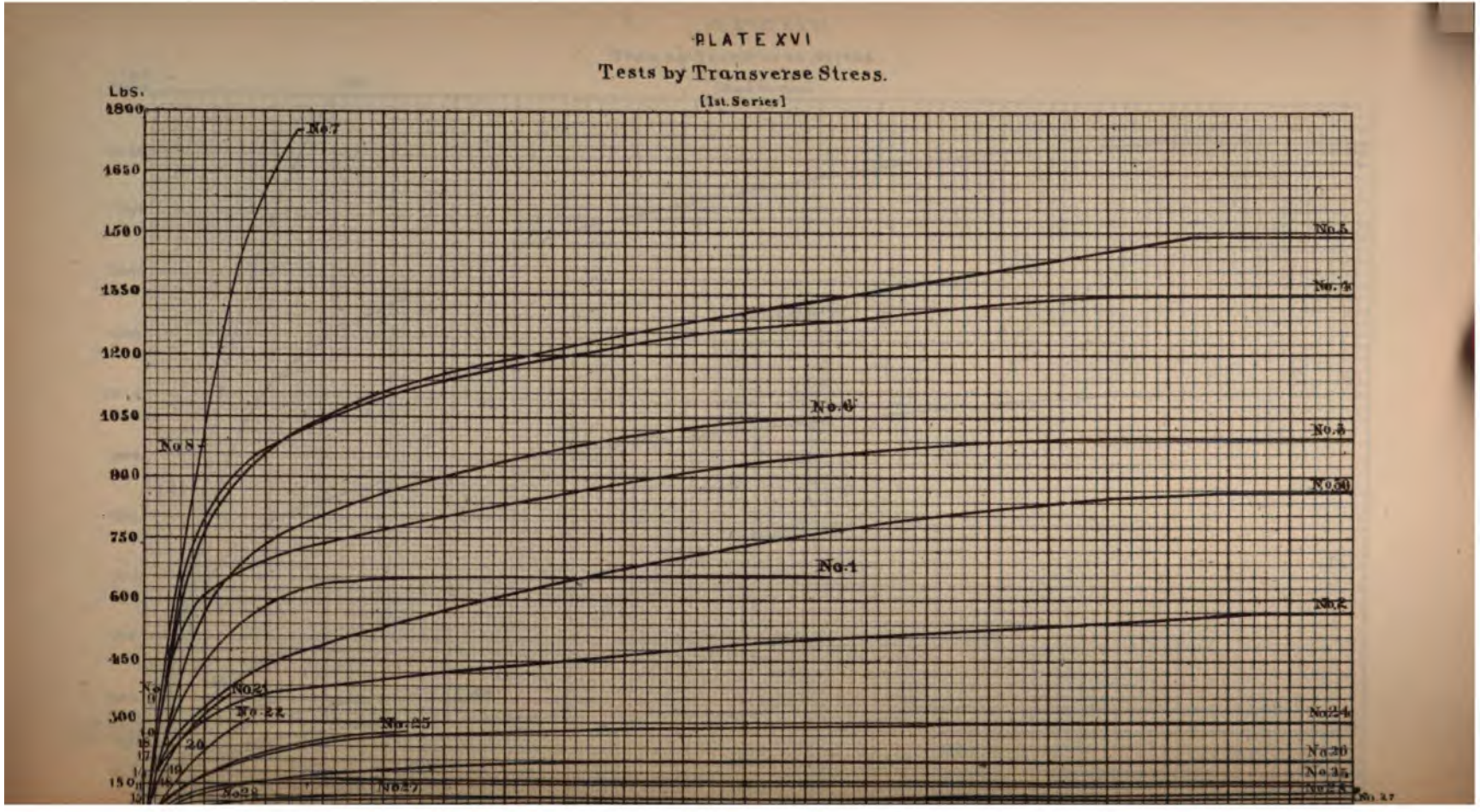


PLATE XVII.

Tests by Transverse Stress.

[2nd. Series.]

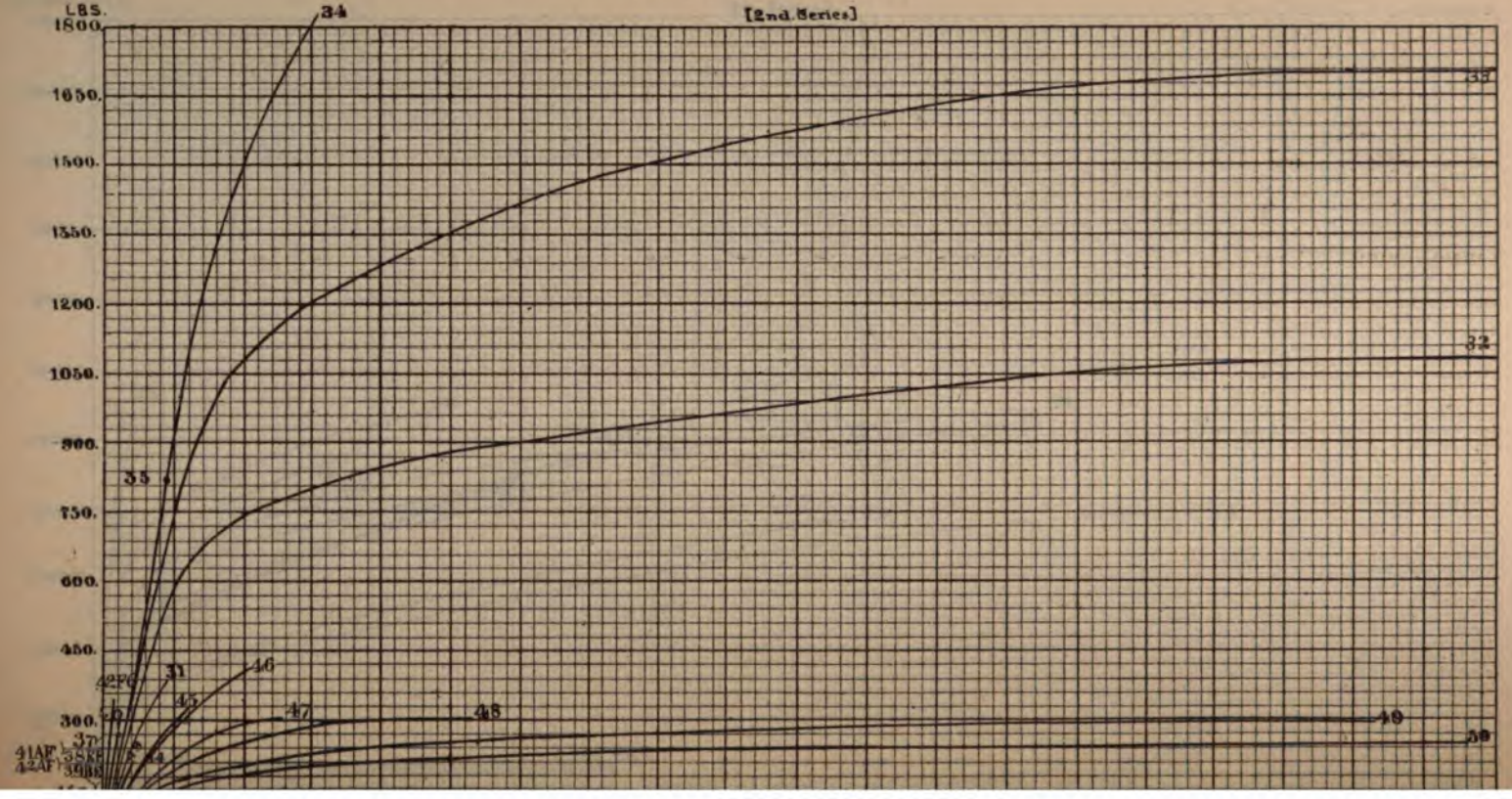
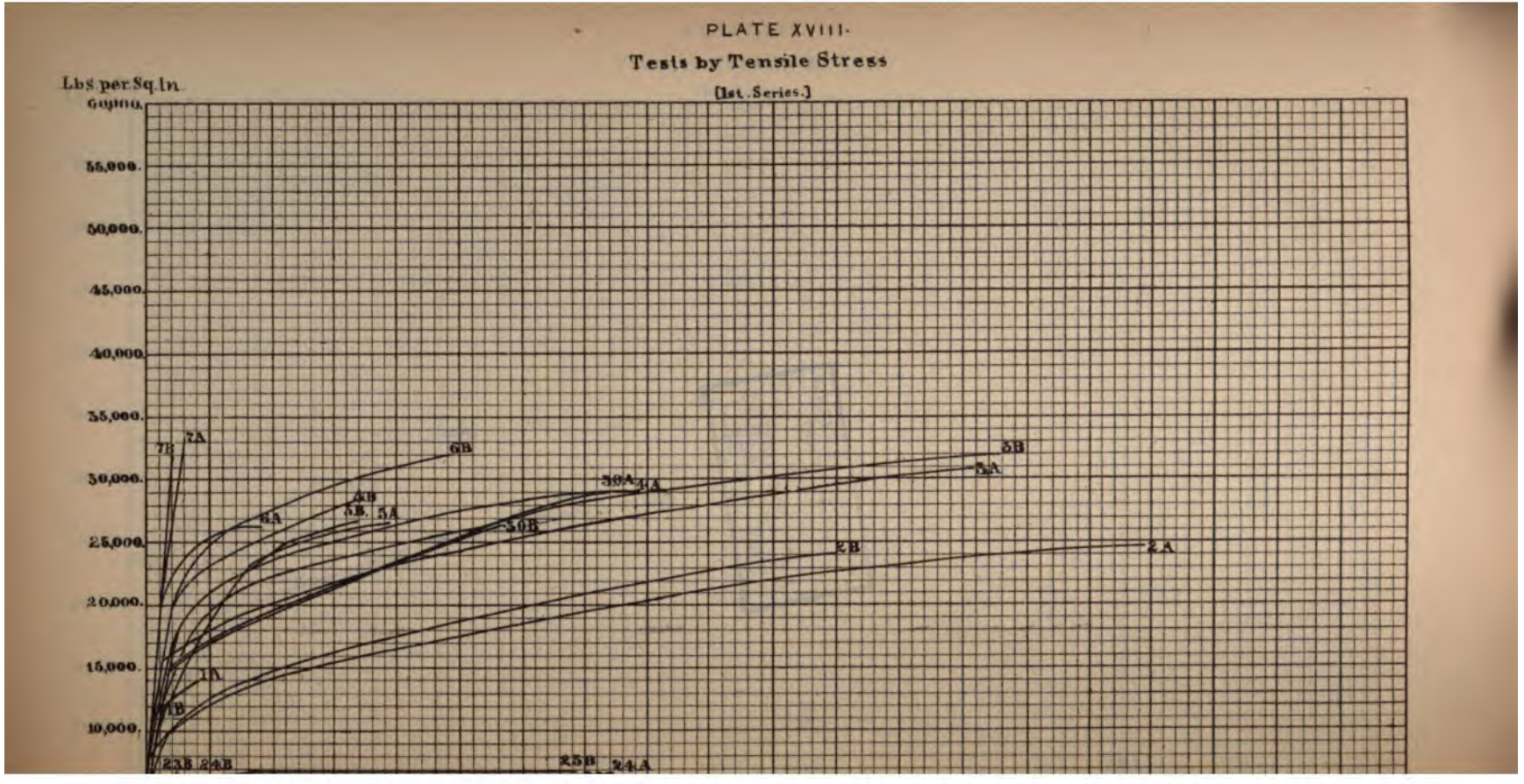


PLATE XVIII.

Tests by Tensile Stress

[1st. Series.]


Lbs per Sq In
60,000.
55,000.
50,000.
45,000.
40,000.
35,000.
30,000.
25,000.
20,000.
15,000.
10,000.
7B
7A
6B
6A
4B
5B
5A
4A
3B
3A
3B
3A
3B
3

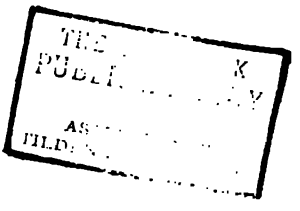
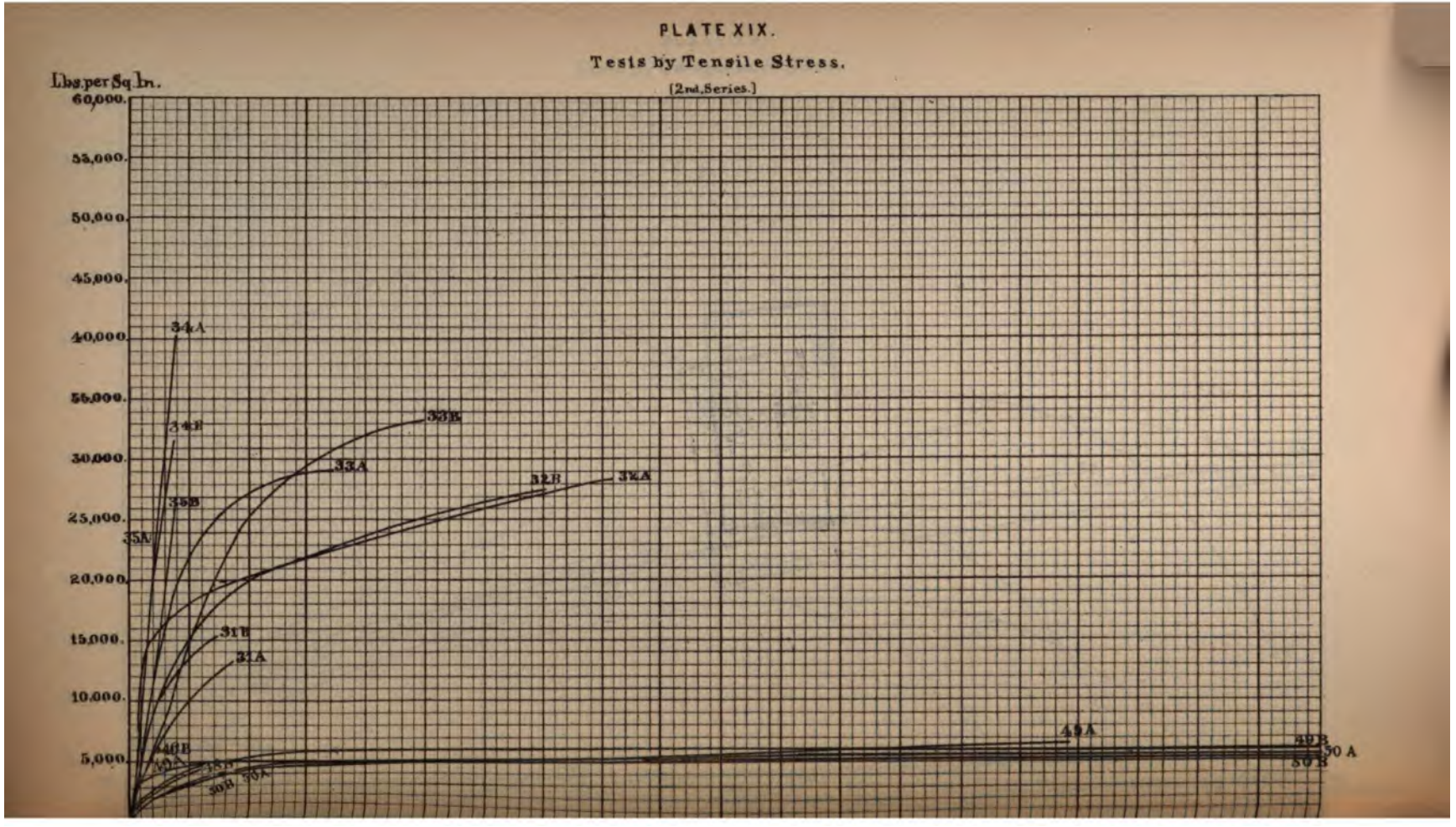

THE
PUBLIC
ASTOR
TILDEN

PLATE XIX.

Tests by Tensile Stress.

[2nd. Series.]



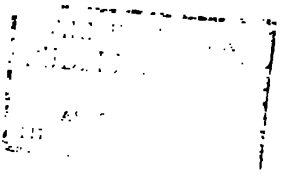
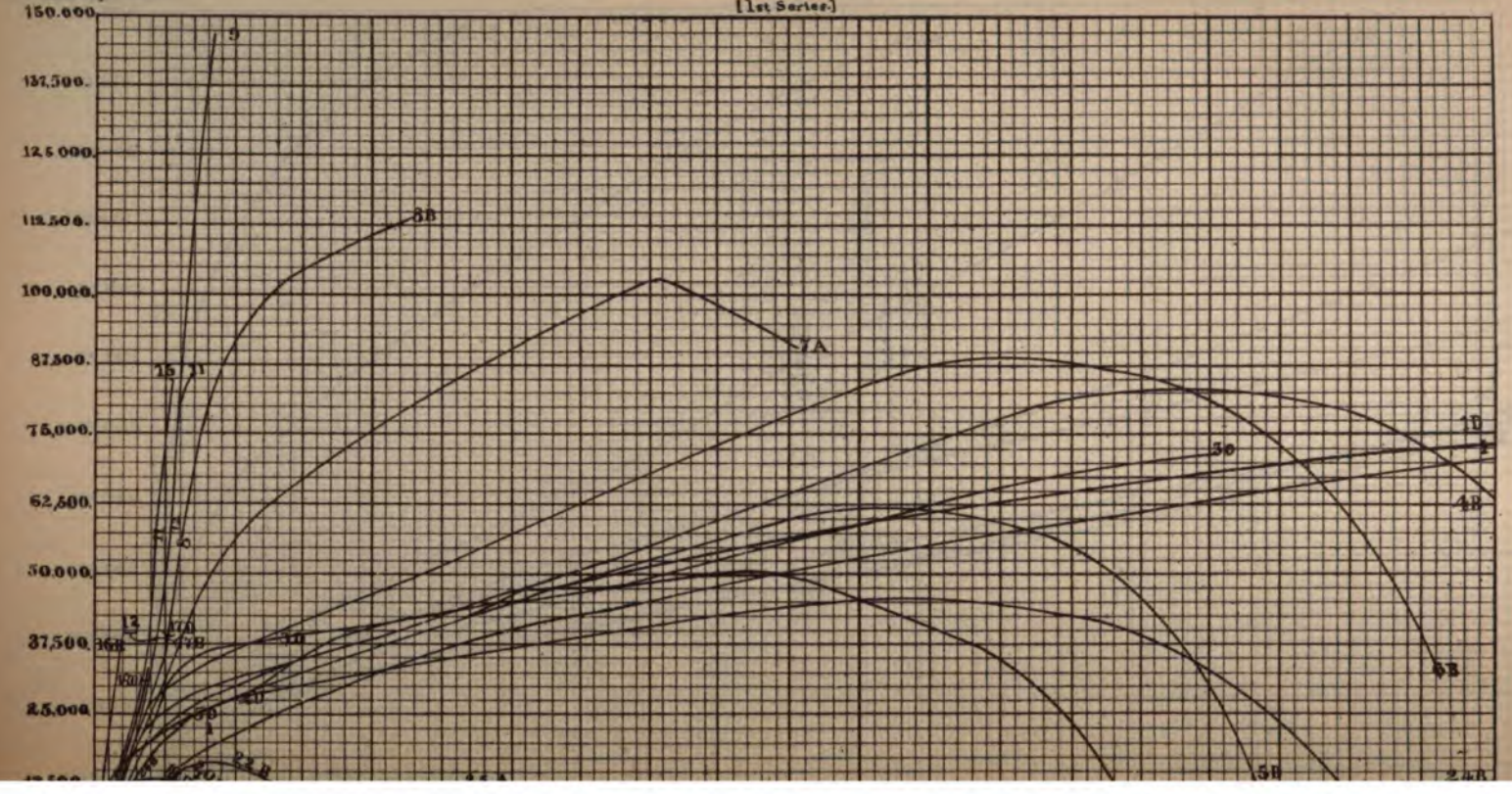


PLATE XX

Tests by Compressive Stress.

[1st Series.]



PLATES XXII–LXXVI.

FAC-SIMILE

TOGRAPHIC STRAIN DIAGRAMS

OF

TESTS BY TORSION

IN THE

AUTOGRAPHIC RECORDING TESTING MACHINE

OF

PROF. R. H. THURSTON.

TES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS.

plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scale for a standard specimen, 1″ long x .625″ diam.	
		Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
	Inches.				
	0.625	117.44295	16.8535		
	"	"	"		
	"	"	"		
	"	"	"

KEY TO PLATES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS—Continue

Number of diagram.		Number of plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scal standard spe 1″ long x .62	
				Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
			Inches.				
	C	XXXVIII	"	0.625	20.18		
	D	do	"	"	"		
26	A	XXXIX	"	"	"		
	B	do	"	"	"		
	C	XL	"	"	"		
	D	do	"	"	"		
27	A	XLI	"	"	"		
	B	do	"	"	"		
	C	XLII	"	"	"		
	D	XLIII	"	"	"		
28	A	XLIV	"	117.44295	10.855		
	B	XLV	"	20.18	3.156		
	C	XLVI	"	"	"		
	D	XLVII	"	"	"		
29	A	XLVIII	"	"	"		
	B	XLIX	"	"	"		
	C	L	"	"	"		
	D	LI	"	"	"		
30	A	LII	"	100.81	4		
	B	do	"	"	"		
	C	LIII	"	"	"		
	D	do	"	"	"		
31	A	LIV	"	"	"		
	B	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
32	A	do	"	"	"		
	B	LV	"	"	"		
	C	LVI	"	100.547	5		
	D	do	"	100.81	4		
33	A	LVII	"	"	"		
	B	do	"	100.547″	5		
	C	do	"	100.81	4		
	D	LVIII	"	"	"		
34	A	do	"	"	"		
	B	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
35	A	do	"	"	"		
	B	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
36	A	LIX	0.975	42.152	1.672	11.103	
	B	do	0.980	100.81	4	26.150	
37	A	do	0.970	42.152	1.672	11.276	
	B	do	.975″ x .970″	"	"		
38	A	do	0.975	"	"	11.103	
	B	do	0.945	"	"	12.196	
39	A	do	0.930	"	"	12.793	
40	A	do	0.935	"	"	12.591	
	B	do	0.935	"	"	12.591	
41	A	do	0.930	"	"	12.793	
	B	do	0.925	"	"	13.004	
42	A	do	0.960	"	"	11.630	
	B	do	0.950	"	"	12.005	
	C	do	0.970	"	"	11.276	
43	A	do	0.625	17.06	1.146		
	B	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
44	A	LX	"	"	"		
	B	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
45	A	do	"	"	"		
	C	do	"	"	"		
	D	do	"	"	"		
46	A	do	"	"	"		
	B	do	"	"	"		

PLATES OF FAC-SIMILE AUTOGRAPHIC STRAIN-DIAGRAMS—Continued.

Number of plate.	Diameter of specimen.	Vertical scale of torsional moments.		Equivalent scale for a standard specimen, 1″ long x .625″ diam.	
		Foot-pounds per inch of ordinate.	Constant for friction.	Foot-pounds per inch of ordinate.	Constant for friction.
	Inches.				
	0.625	17.06	1.146		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	117.44295	10.855		
	"	67.86	5.442		
	"	117.44295	10.855		
	"	"	"		
	"	"	"		
	"	100.81	4		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	"	"		
	"	17.011	0.675		
	"	"	"		
	"	"	"		

PLATE XXII.

Fac-Simile Autographic Strain Diagrams.

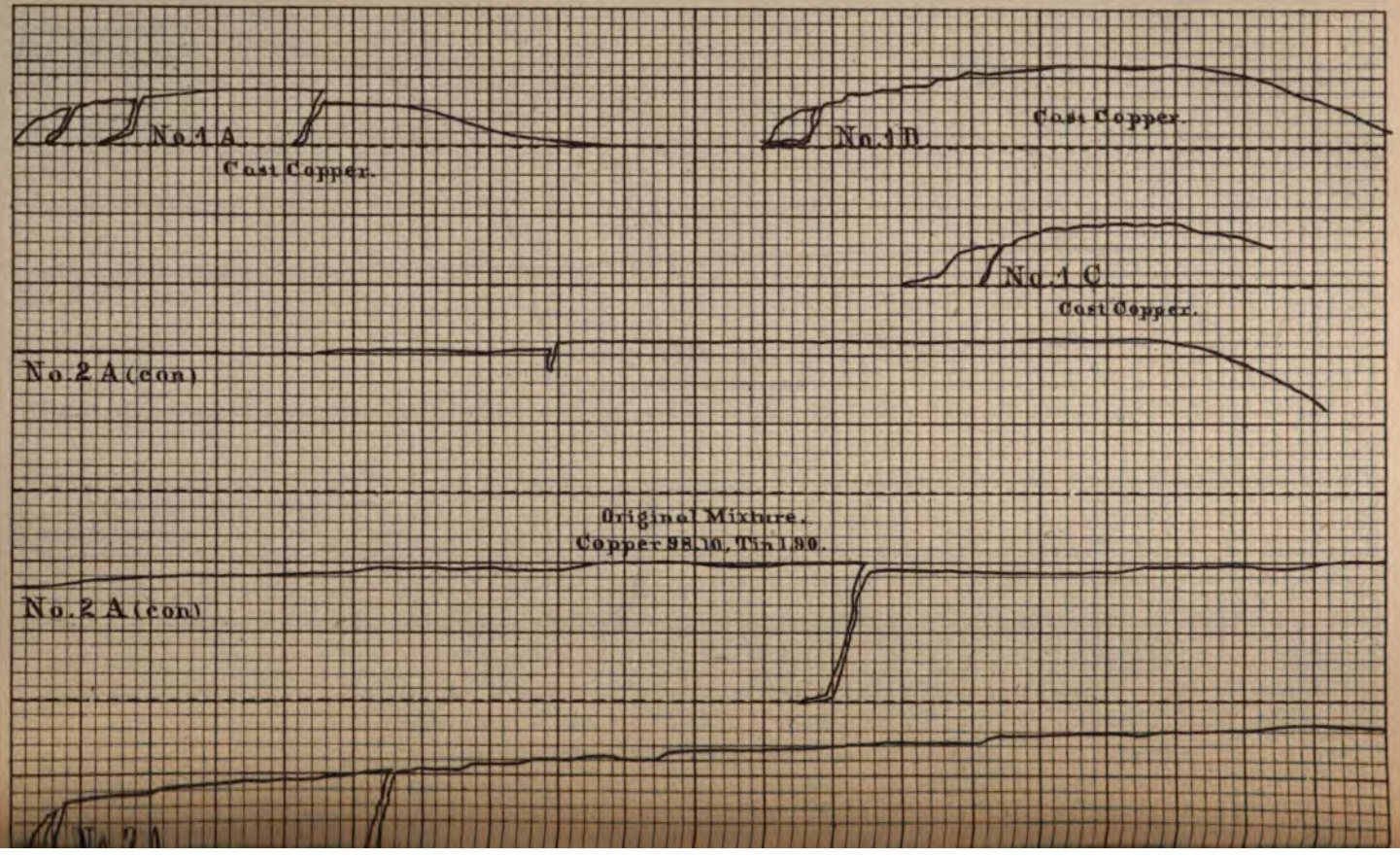


PLATE XXIII.

Fac-Simile Autographic Strain Diagrams.

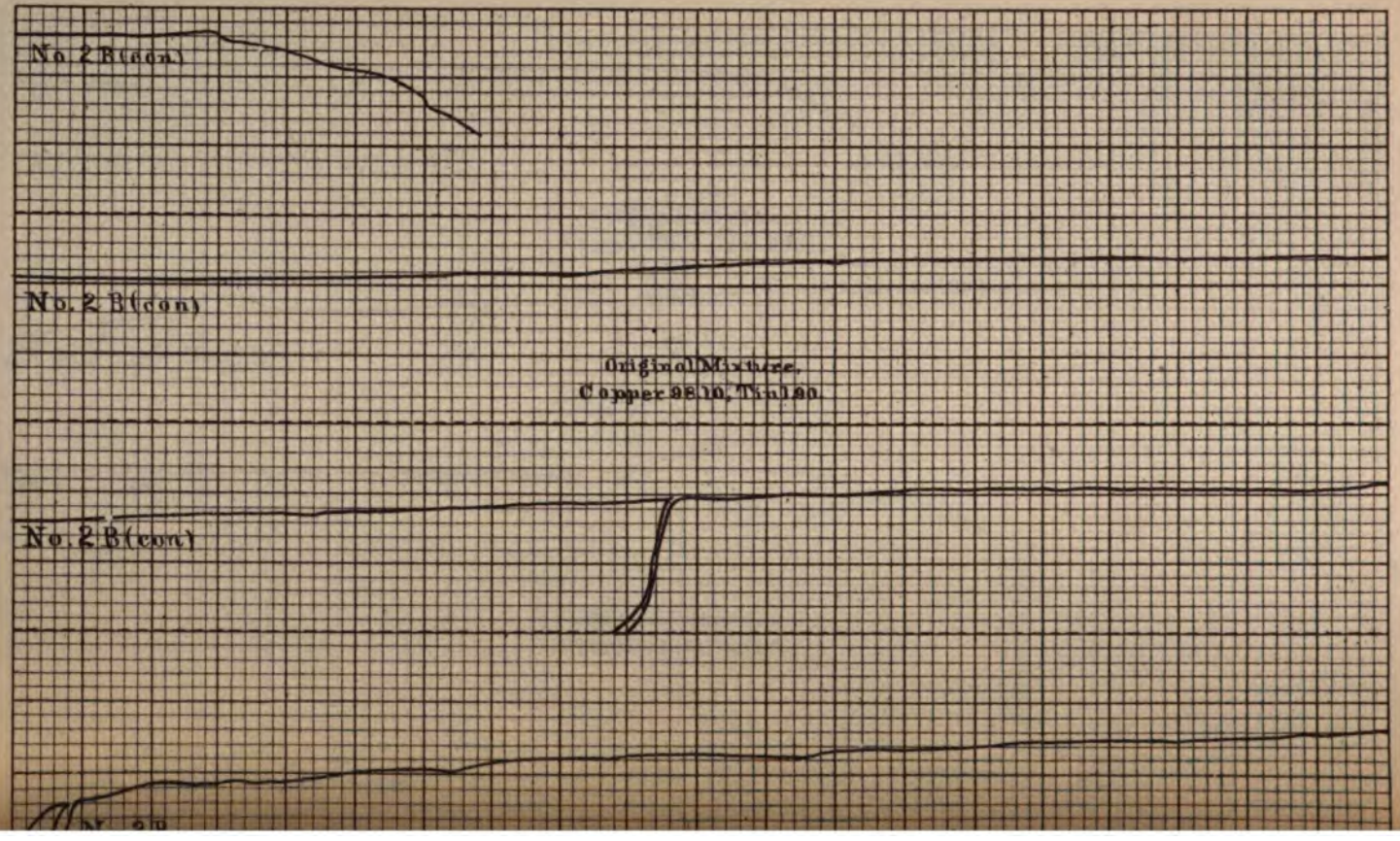
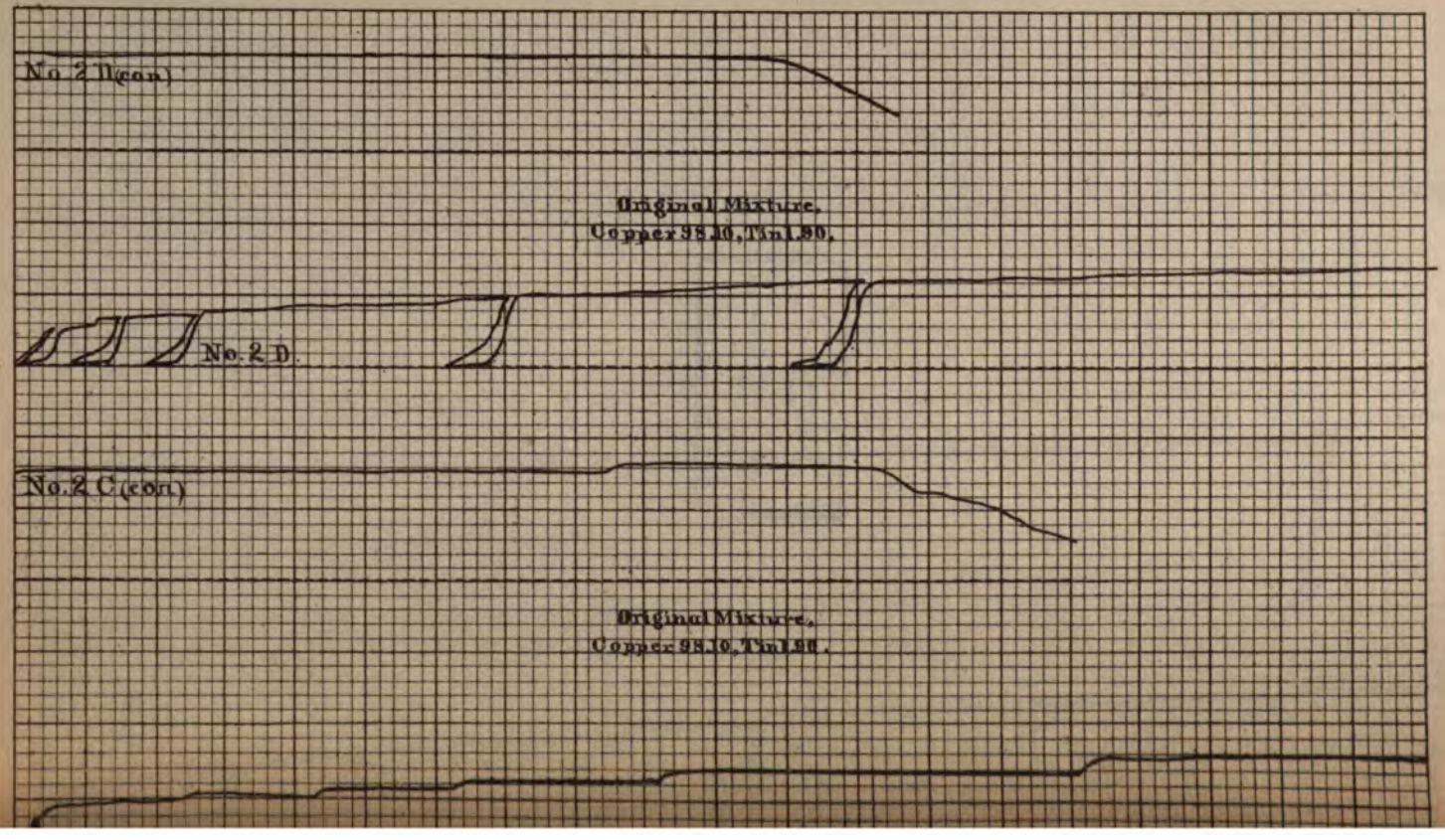


PLATE XXIV.

Fac-Simile Autographic Strain Diagrams.



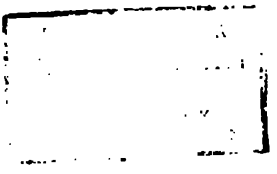


PLATE XXV

Fac-Simile Autographic Strain Diagrams.

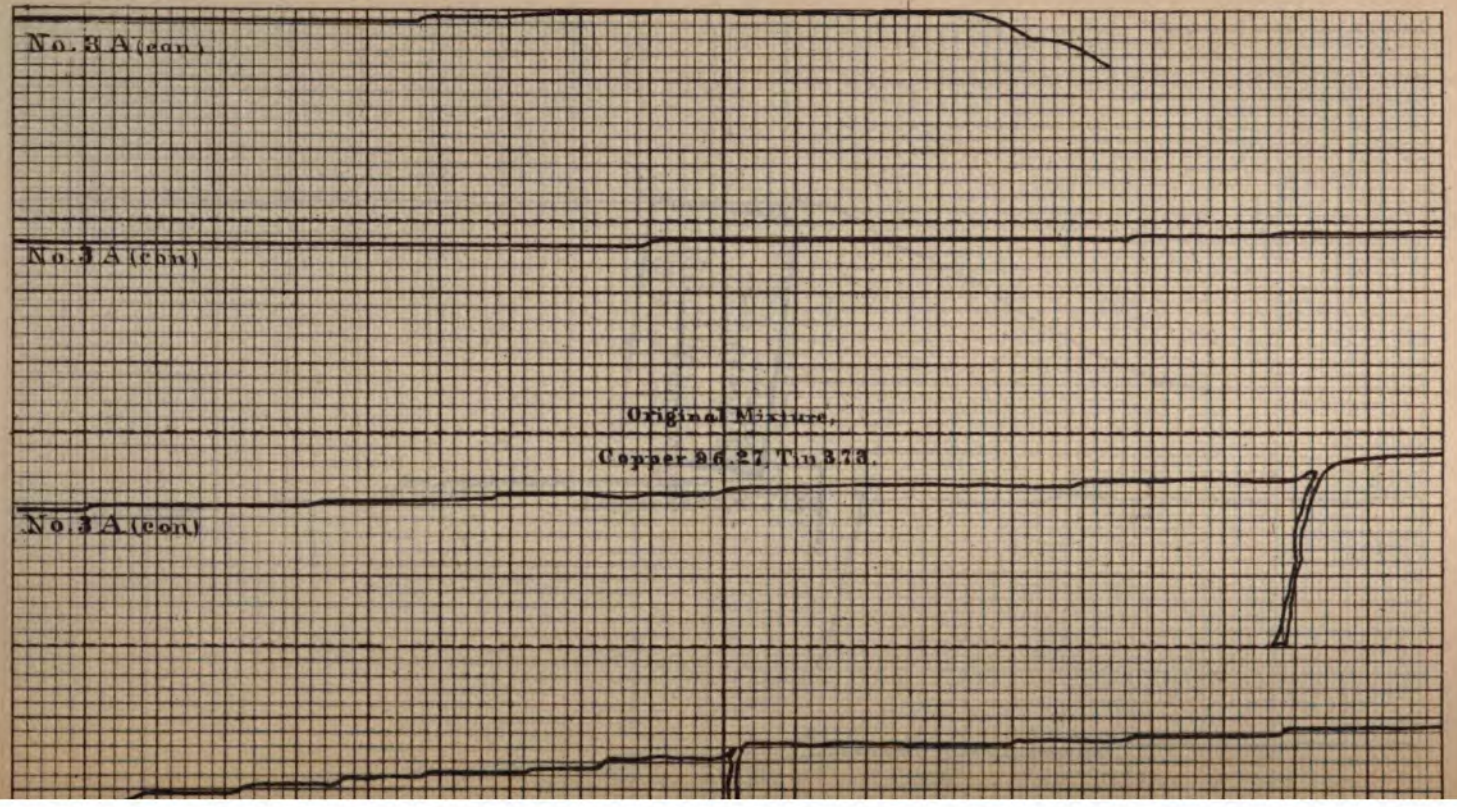


PLATE XXVI.

Fac-Simile Autographic Strain Diagrams.

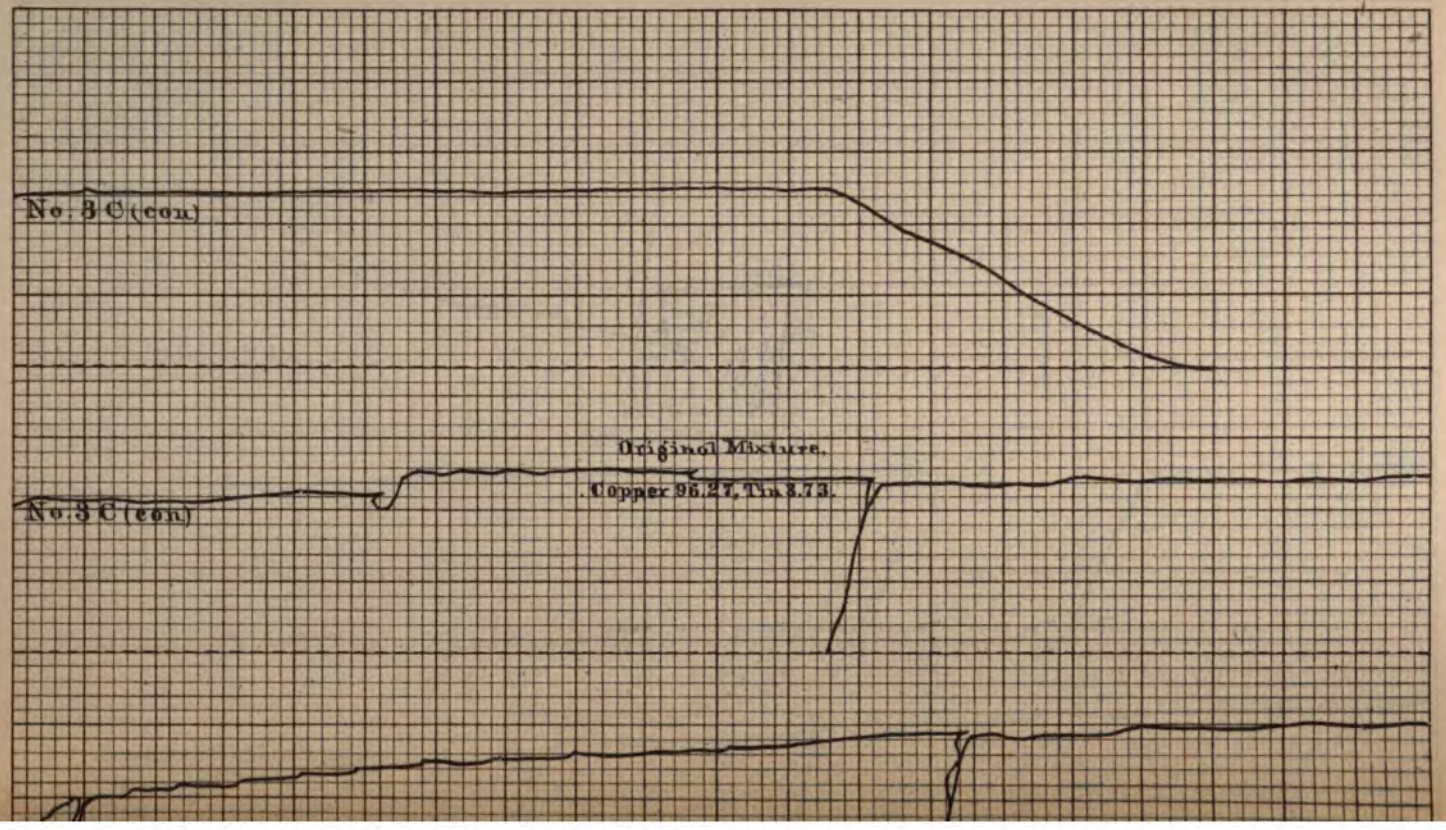


PLATE XXVII.

Fac-Simile Autographic Strain Diagrams.

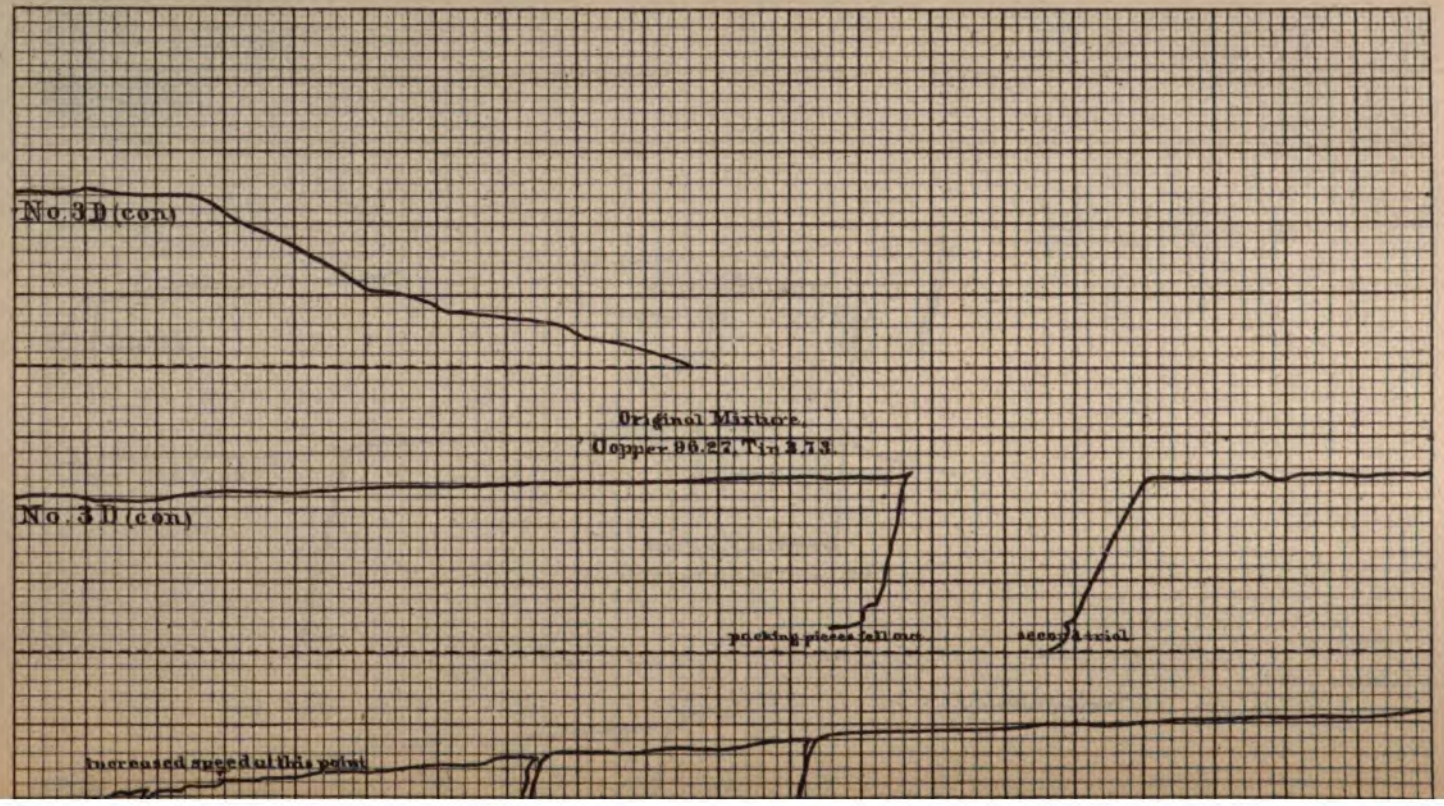


PLATE XXVIII.

Fac-Simile Autographic Strain Diagrams.

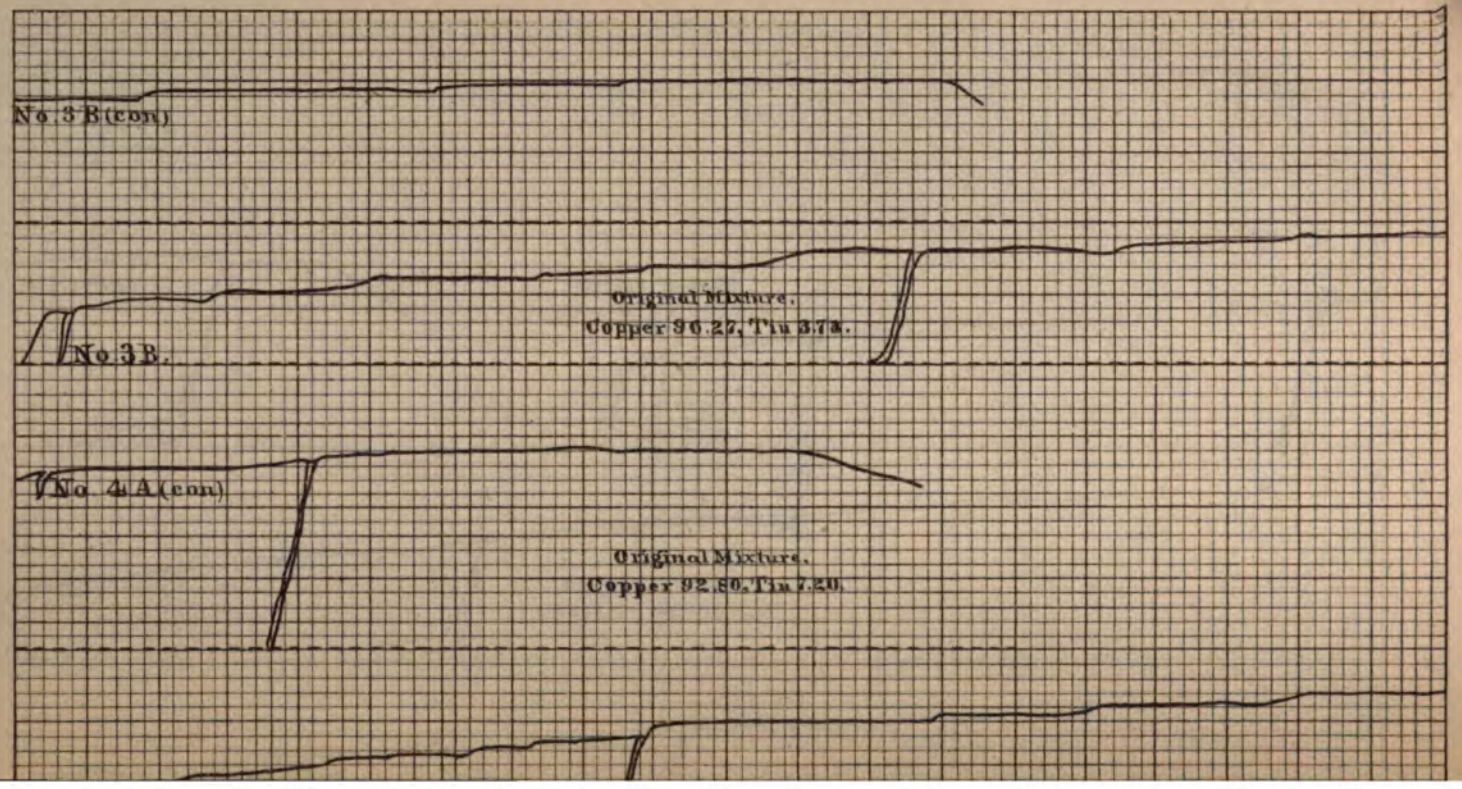


PLATE XXIX.

Fac-Simile Autographic Strain Diagrams.

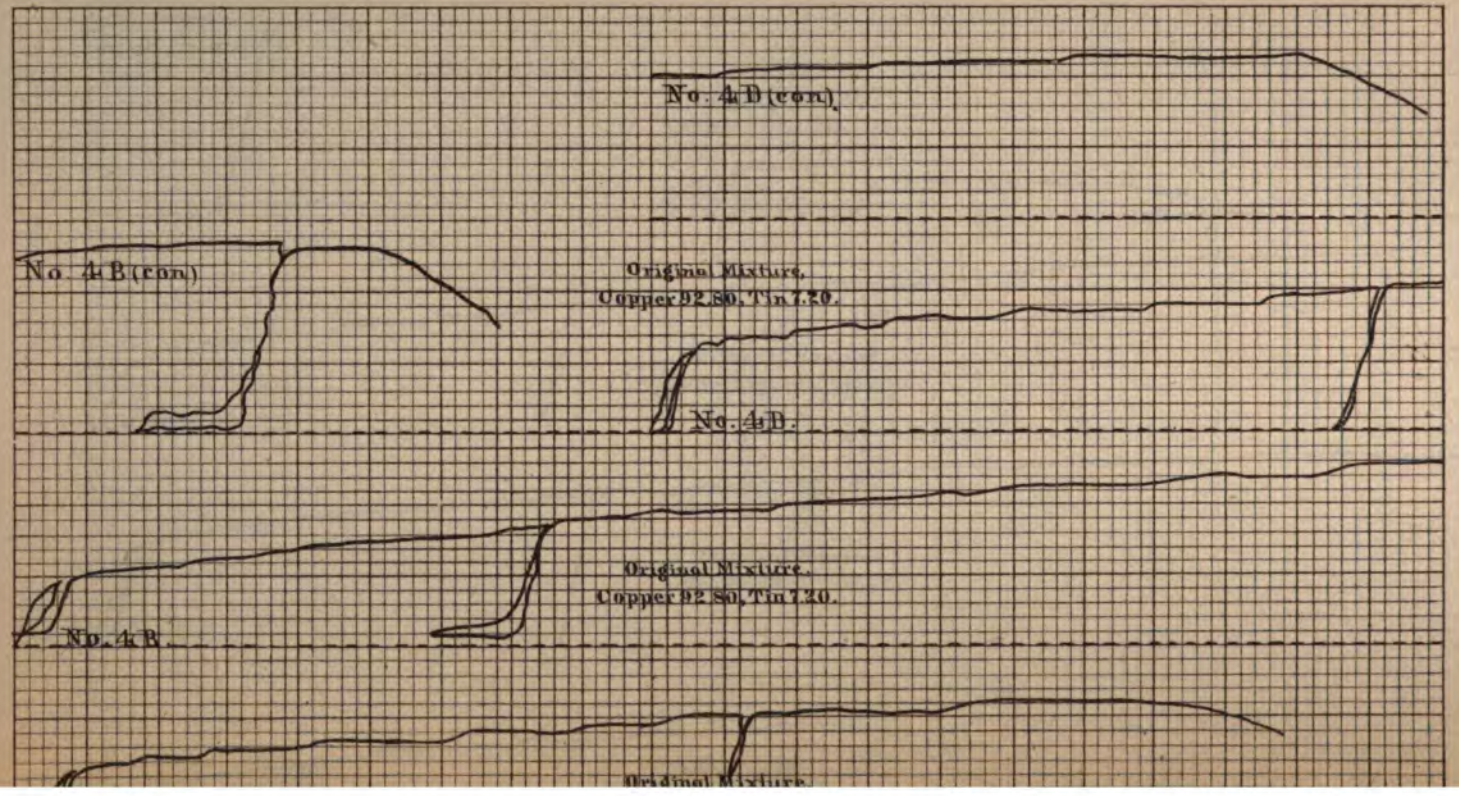
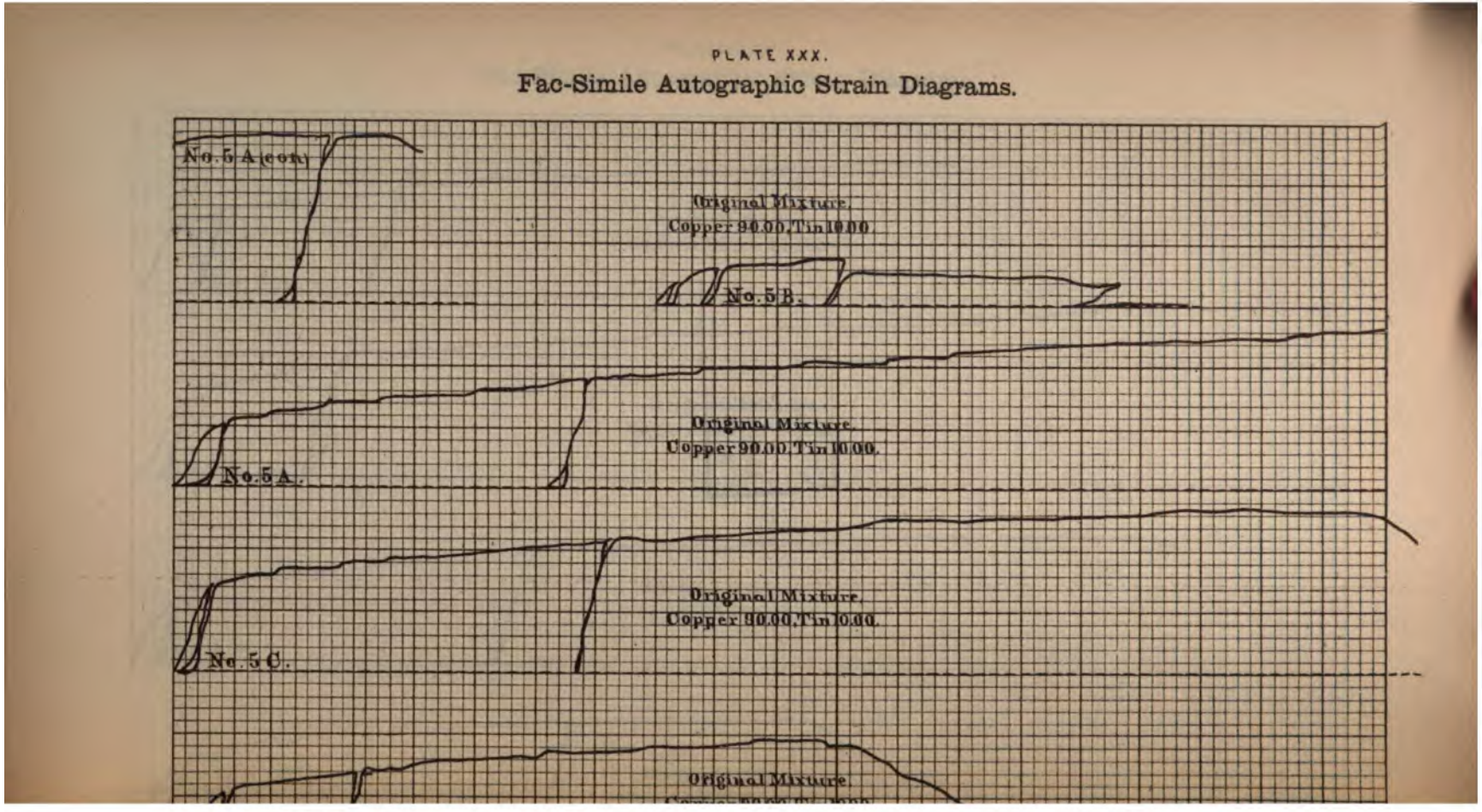


PLATE XXX.

Fac-Simile Autographic Strain Diagrams.



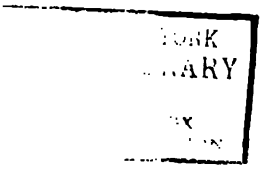
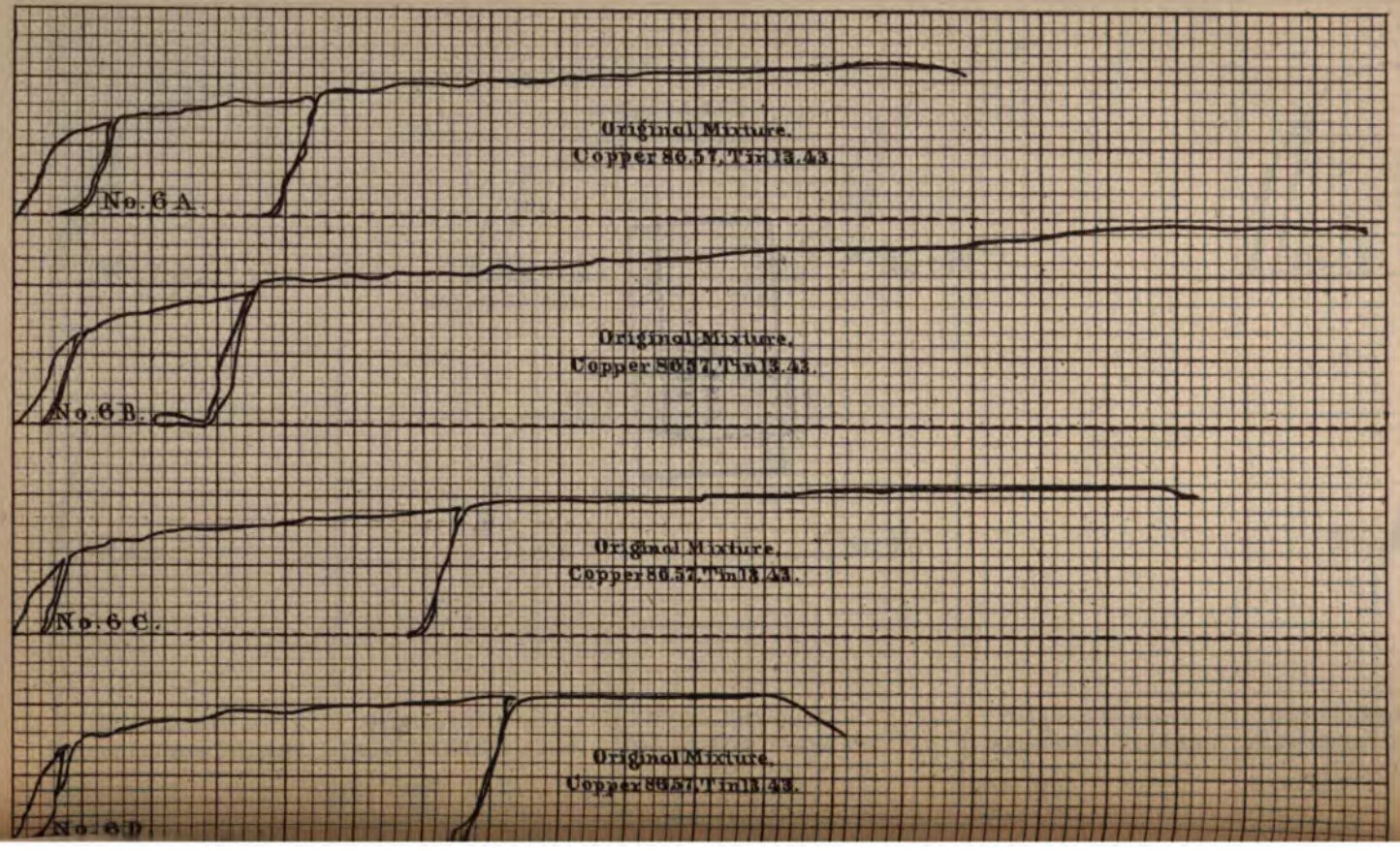


PLATE XXXI.

Fac-Simile Autographic Strain Diagrams.



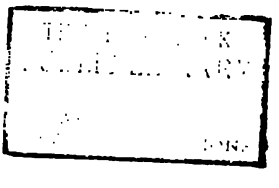
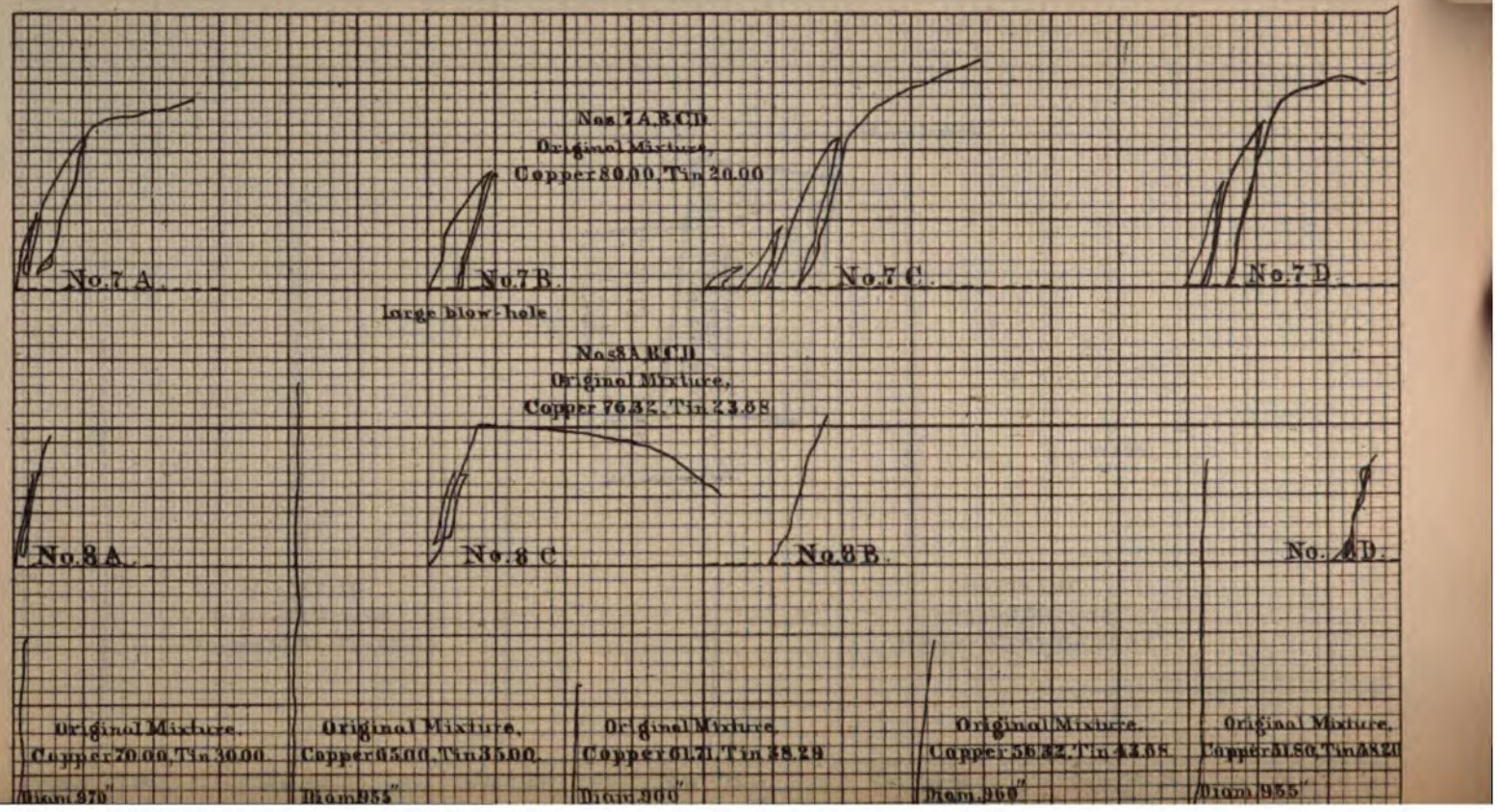


PLATE XXXII.

Fac-Simile Autographic Strain Diagrams.



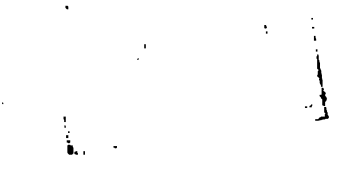
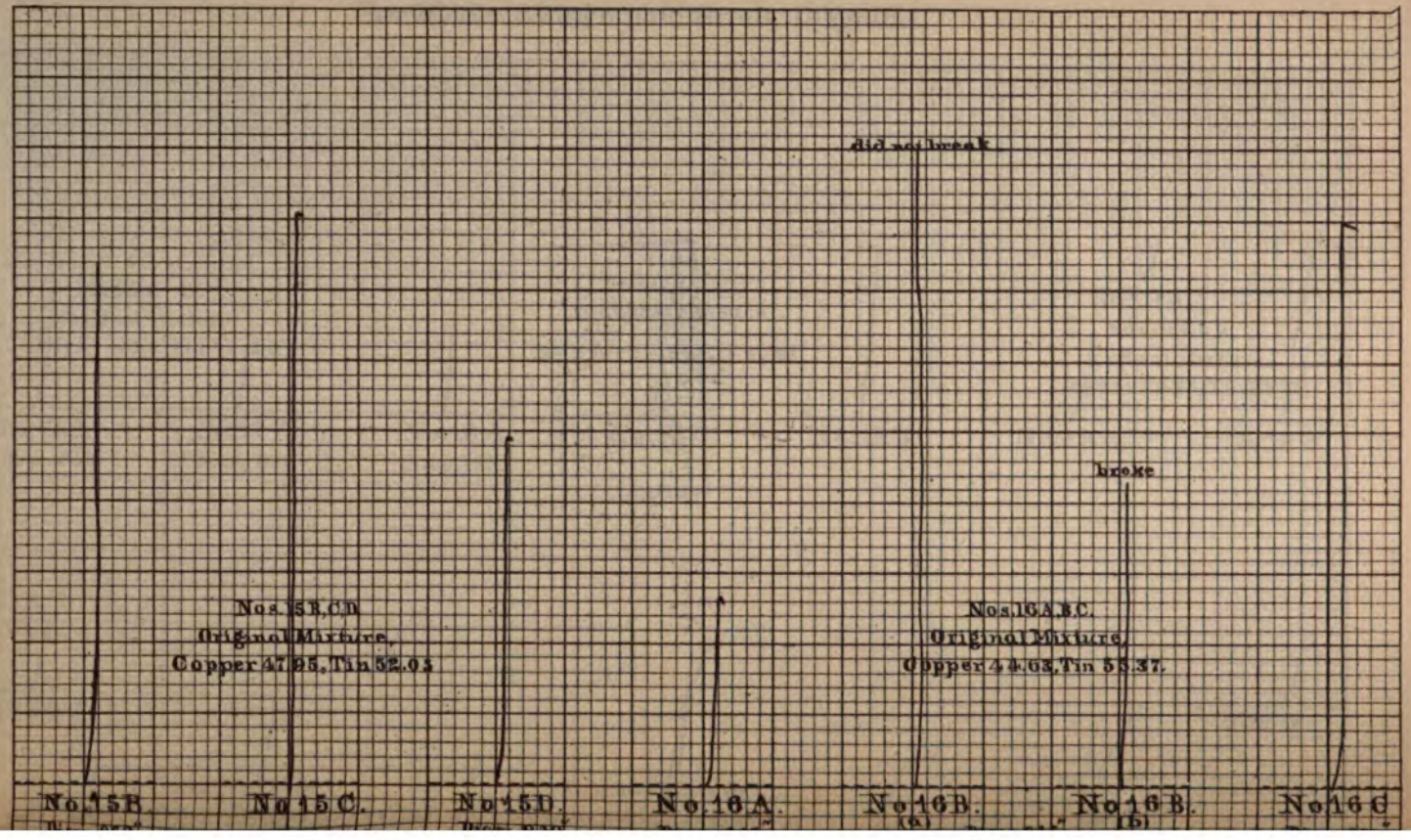


PLATE XXXIII

Fac-Simile Autographic Strain Diagrams.



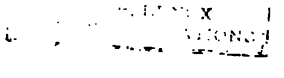


PLATE XXXIV

Fac-Simile Autographic Strain Diagrams.

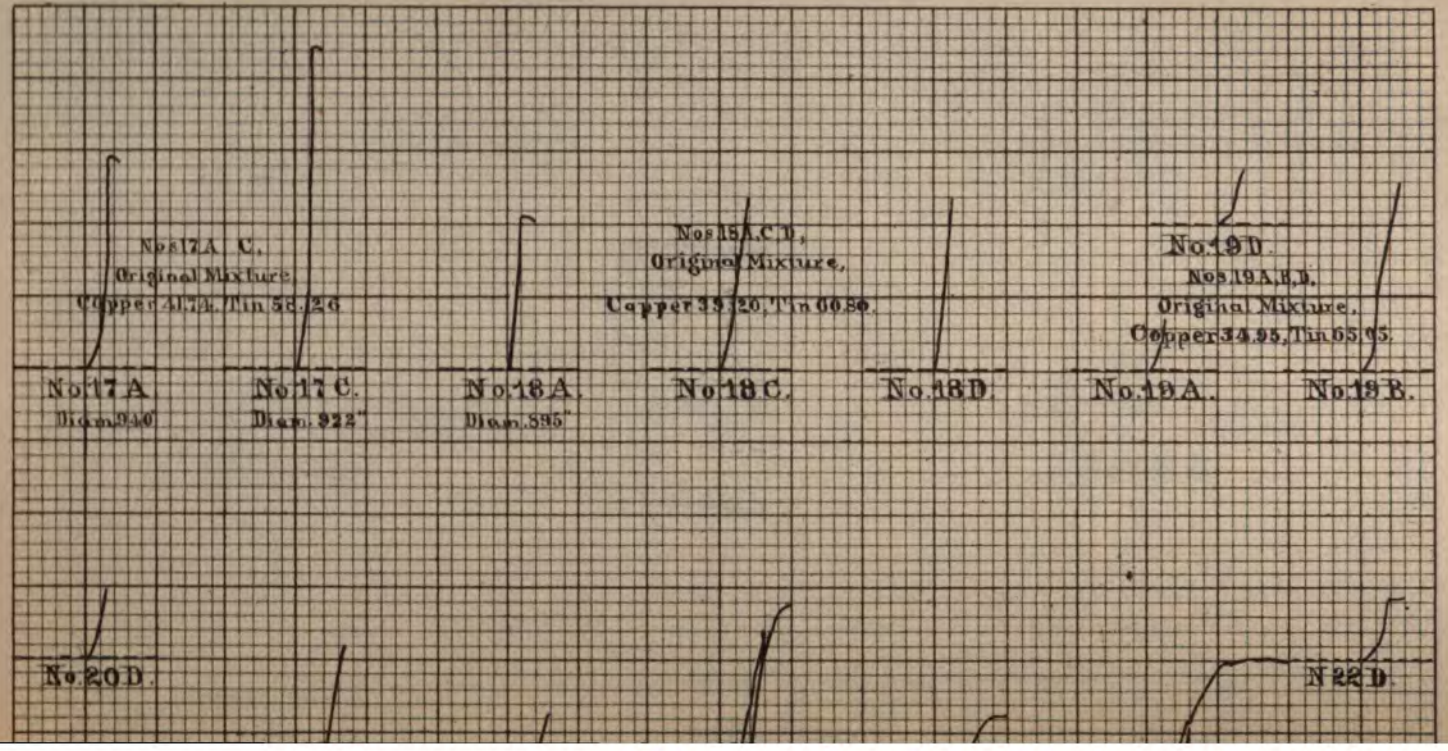


PLATE XXXV.

Fac-Simile Autographic Strain Diagrams.

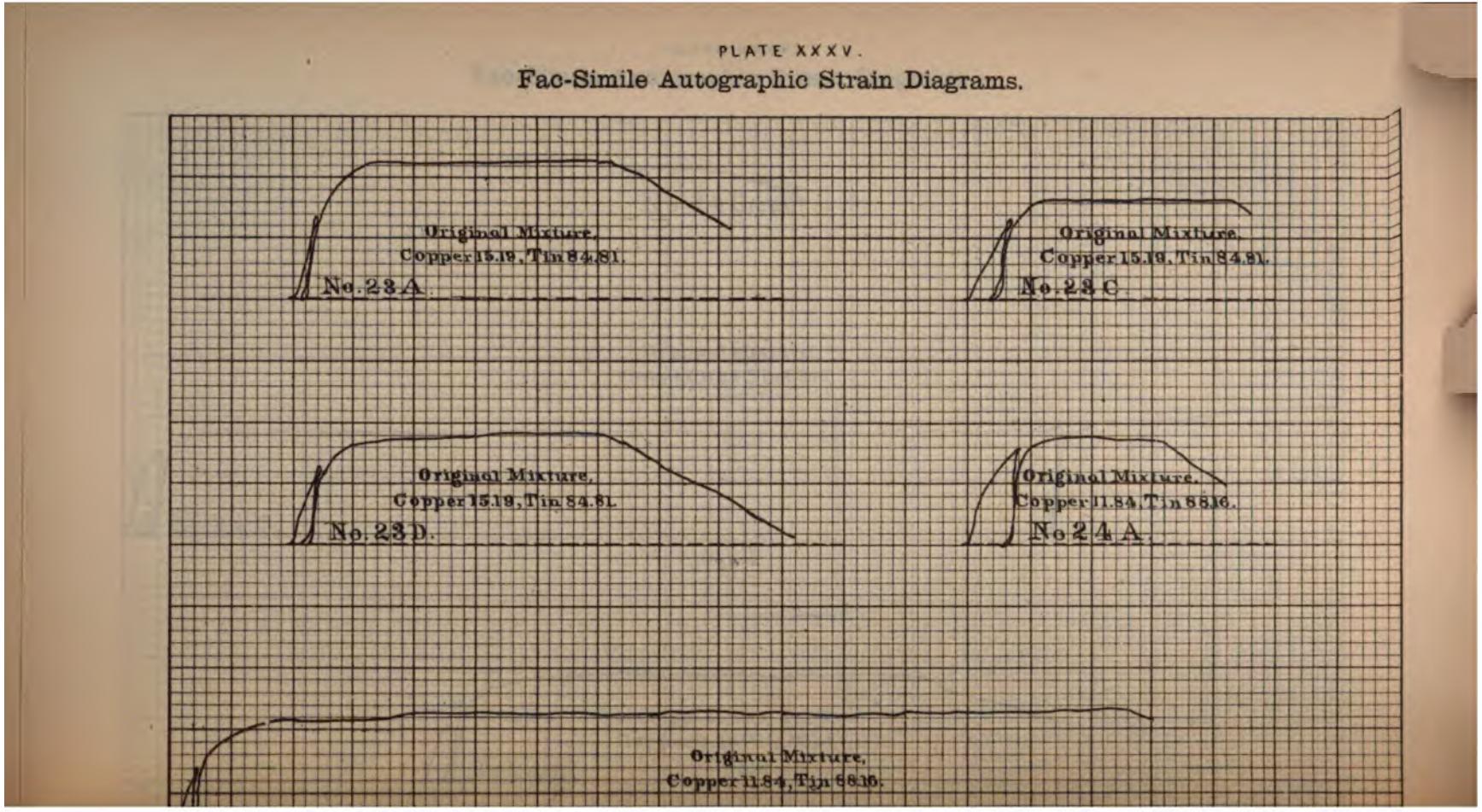


PLATE XXXVI.

Fac-Simile Autographic Strain Diagrams.

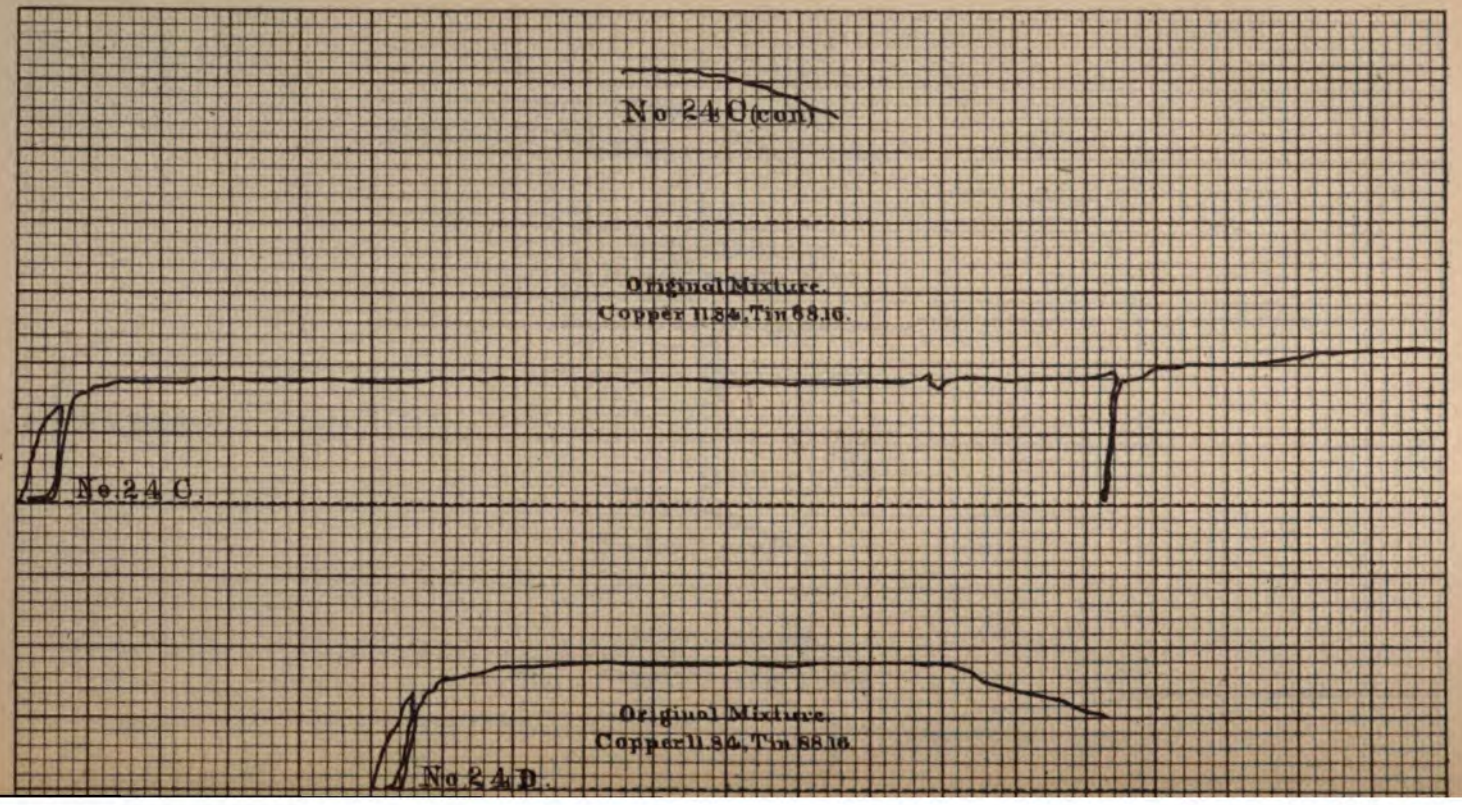
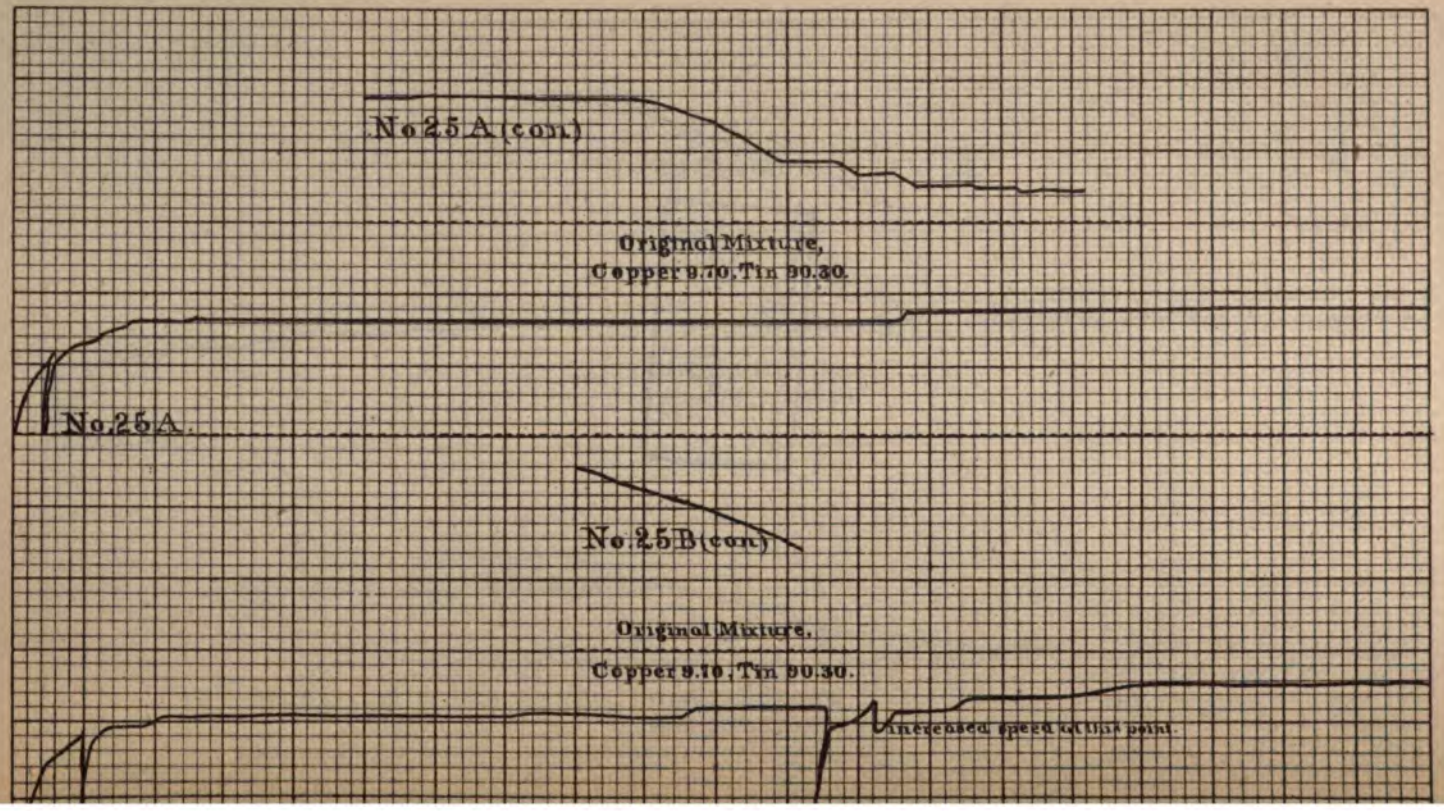


PLATE XXXVII.

Fac-Simile Autographic Strain Diagrams.



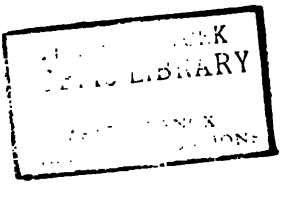

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PLATE XXXVIII.

Fac-Simile Autographic Strain Diagrams.

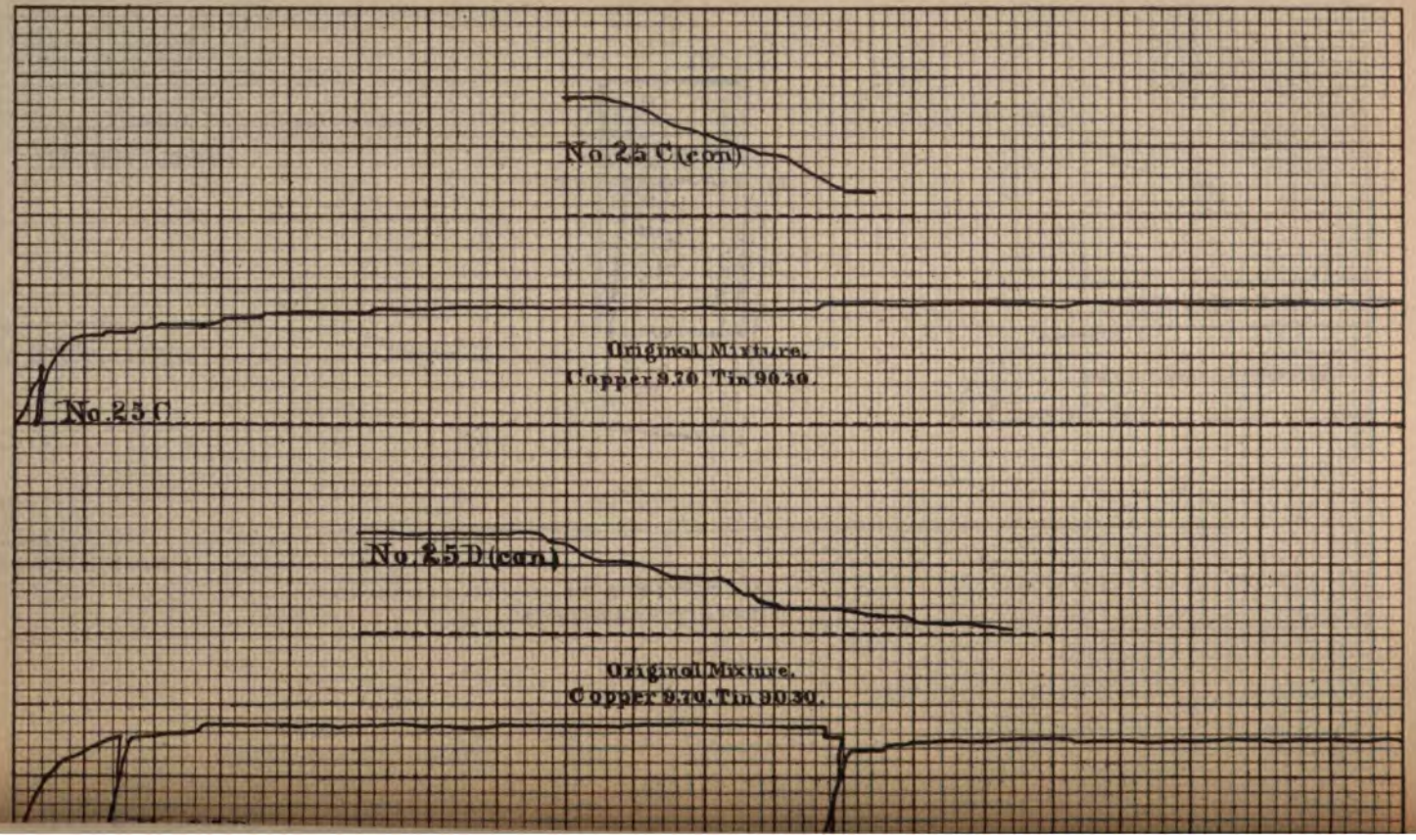

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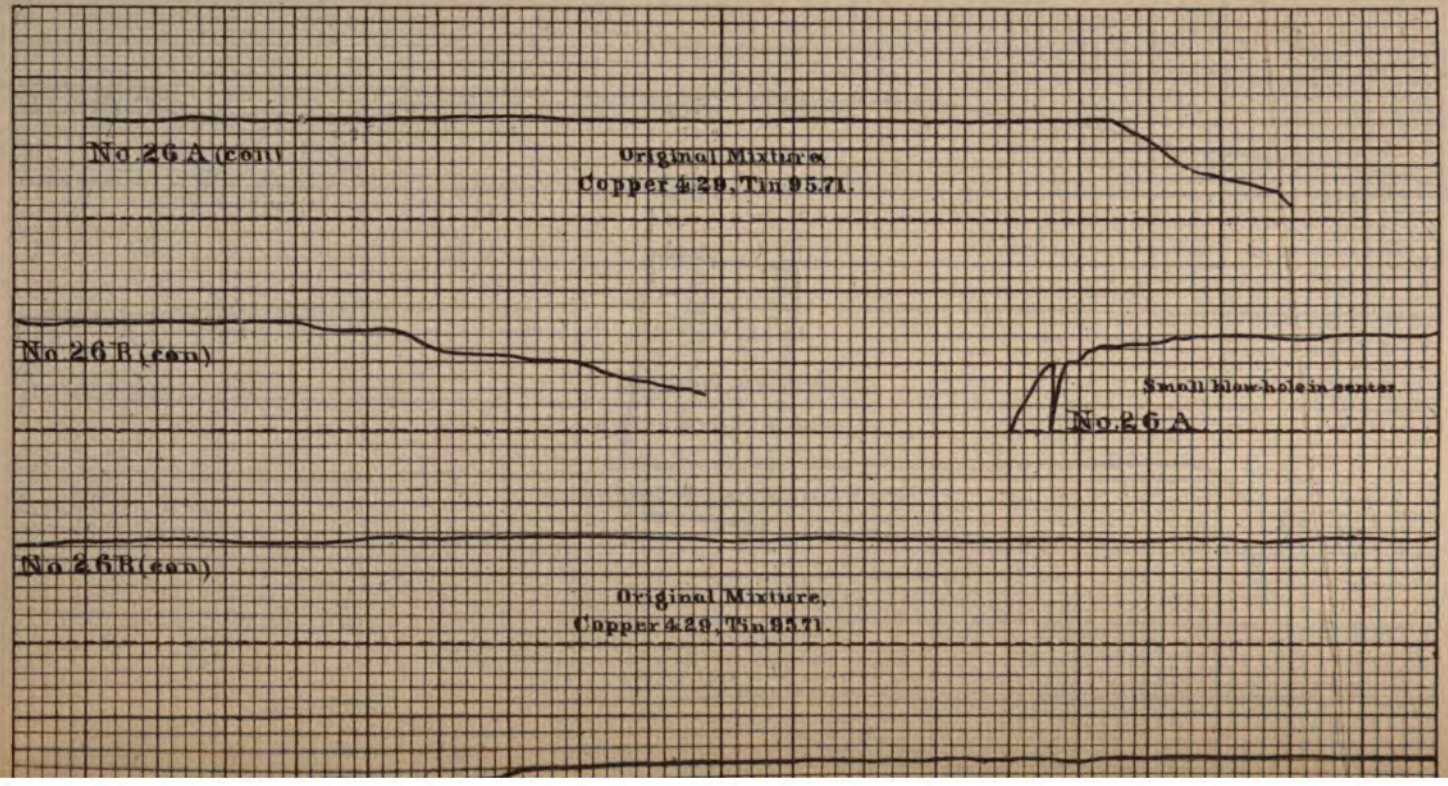
PLATE XXXIX.

Fac-Simile Autographic Strain Diagrams.



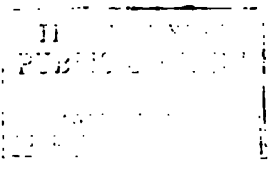
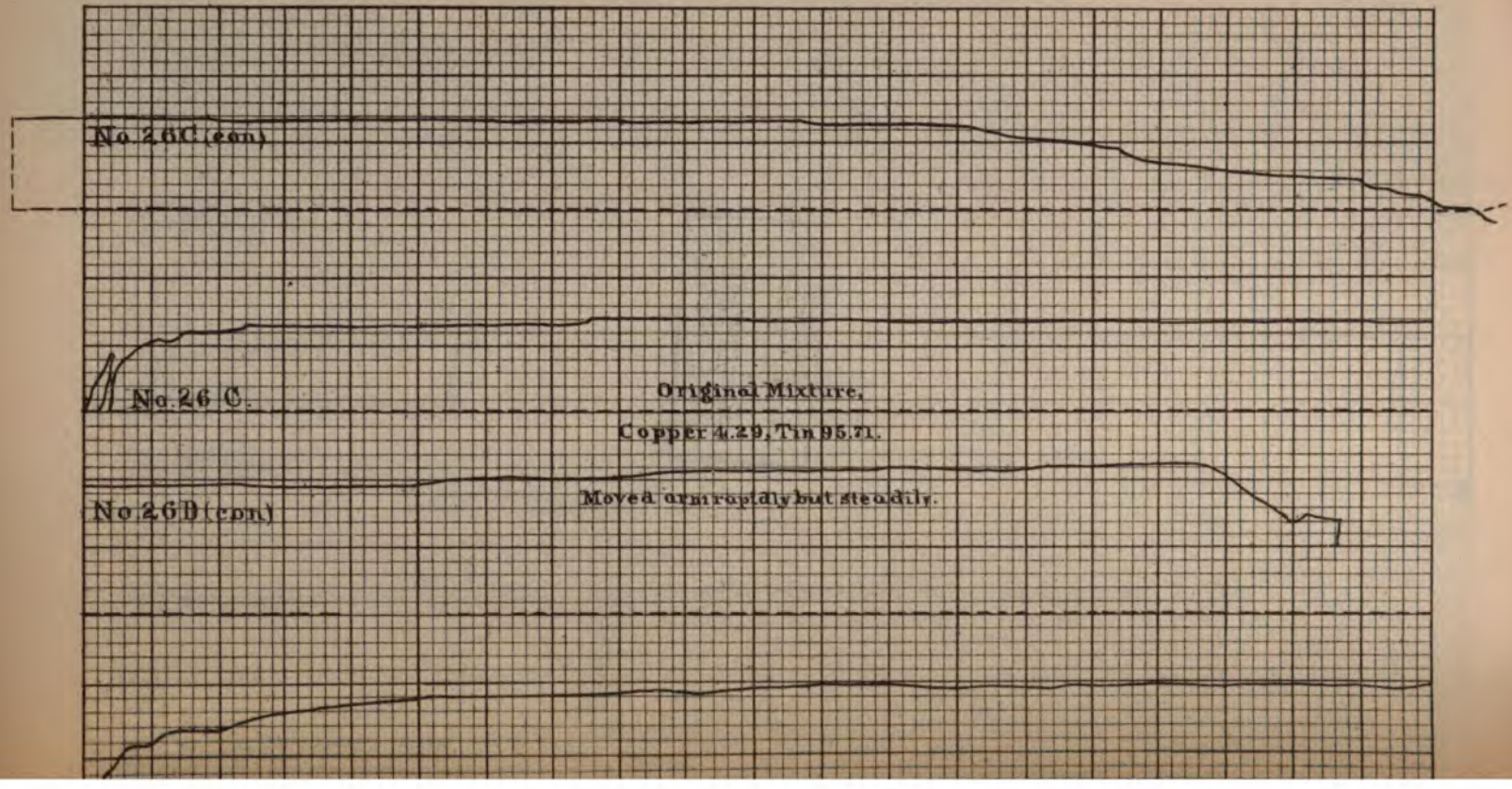


PLATE XL.

Fac-Simile Autographic Strain Diagrams.



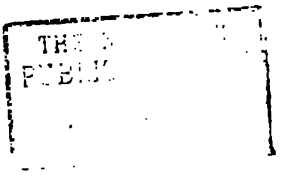


PLATE XLI.

Fac-Simile Autographic Strain Diagrams.

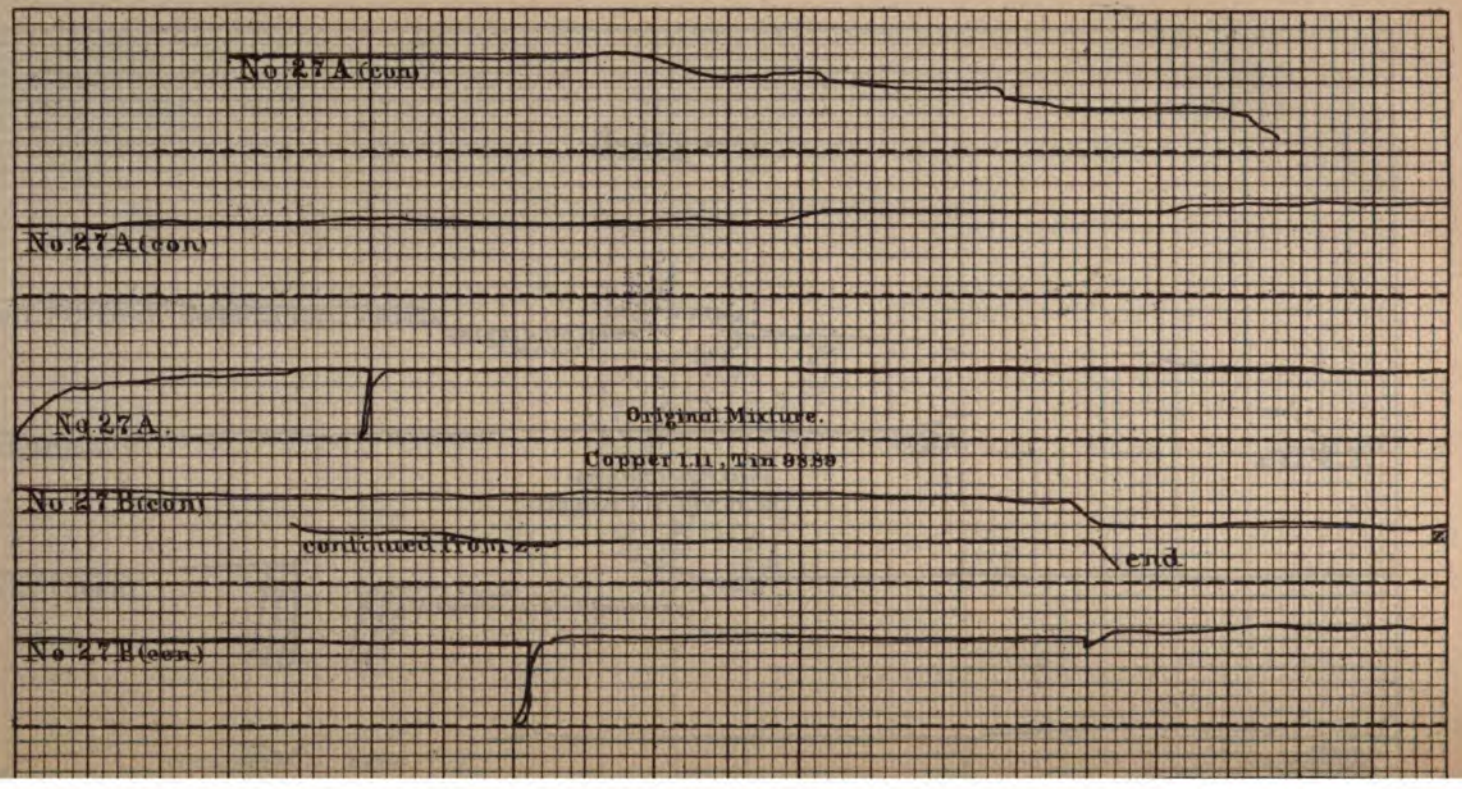


PLATE XLII.

Fac-Simile Autographic Strain Diagrams.

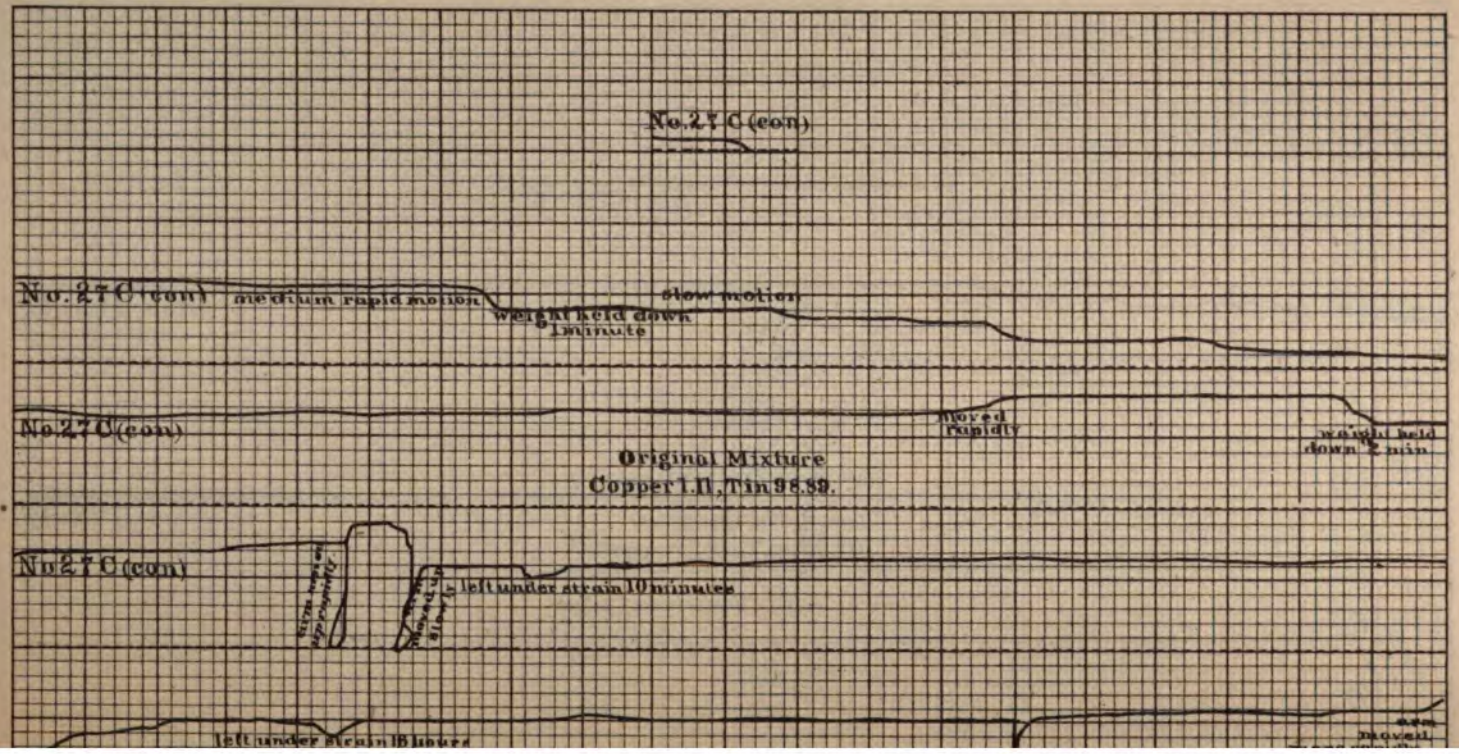
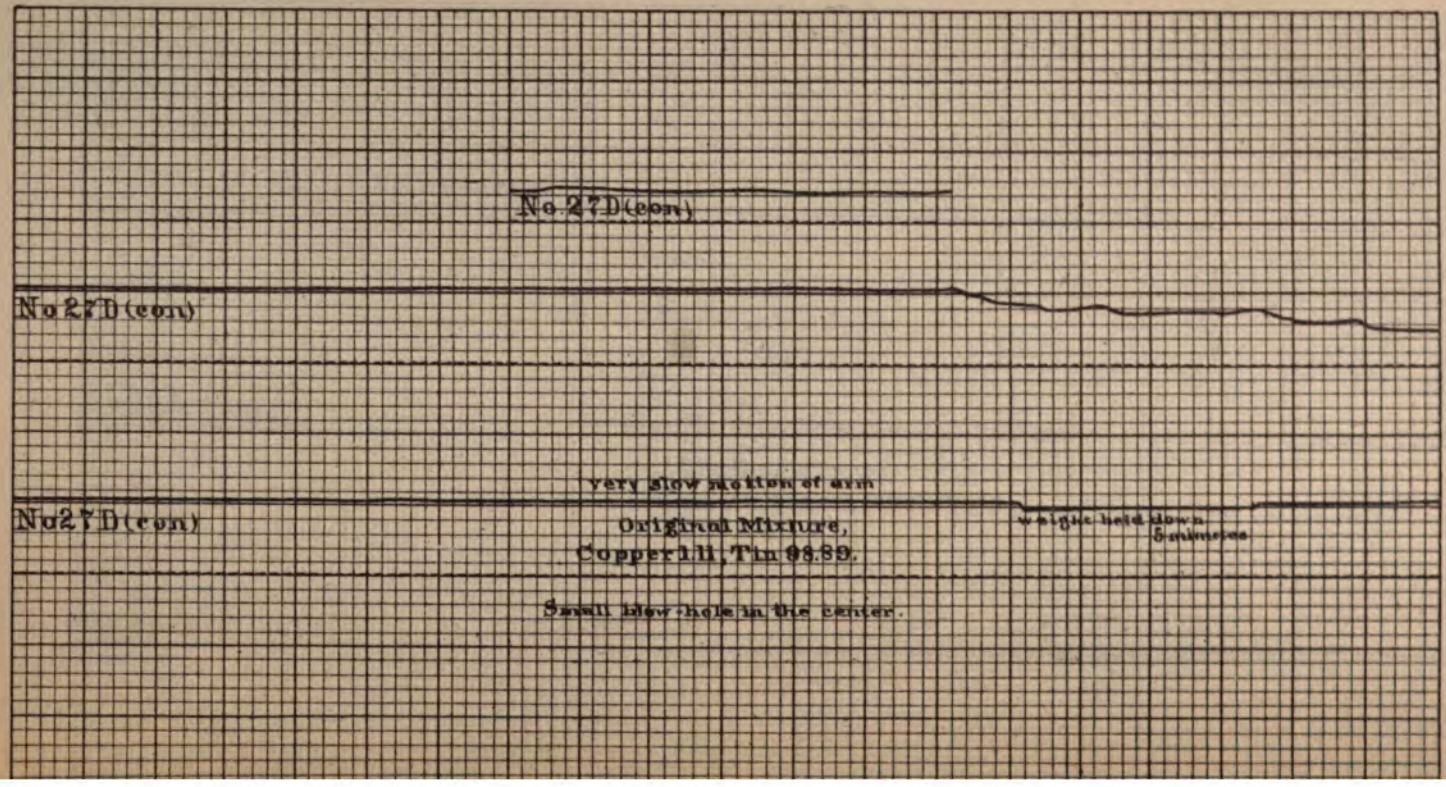


PLATE XLIII.

Fac-Simile Autographic Strain Diagrams.



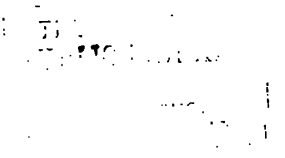


PLATE XLIV.

Fac-Simile Autographic Strain Diagrams.

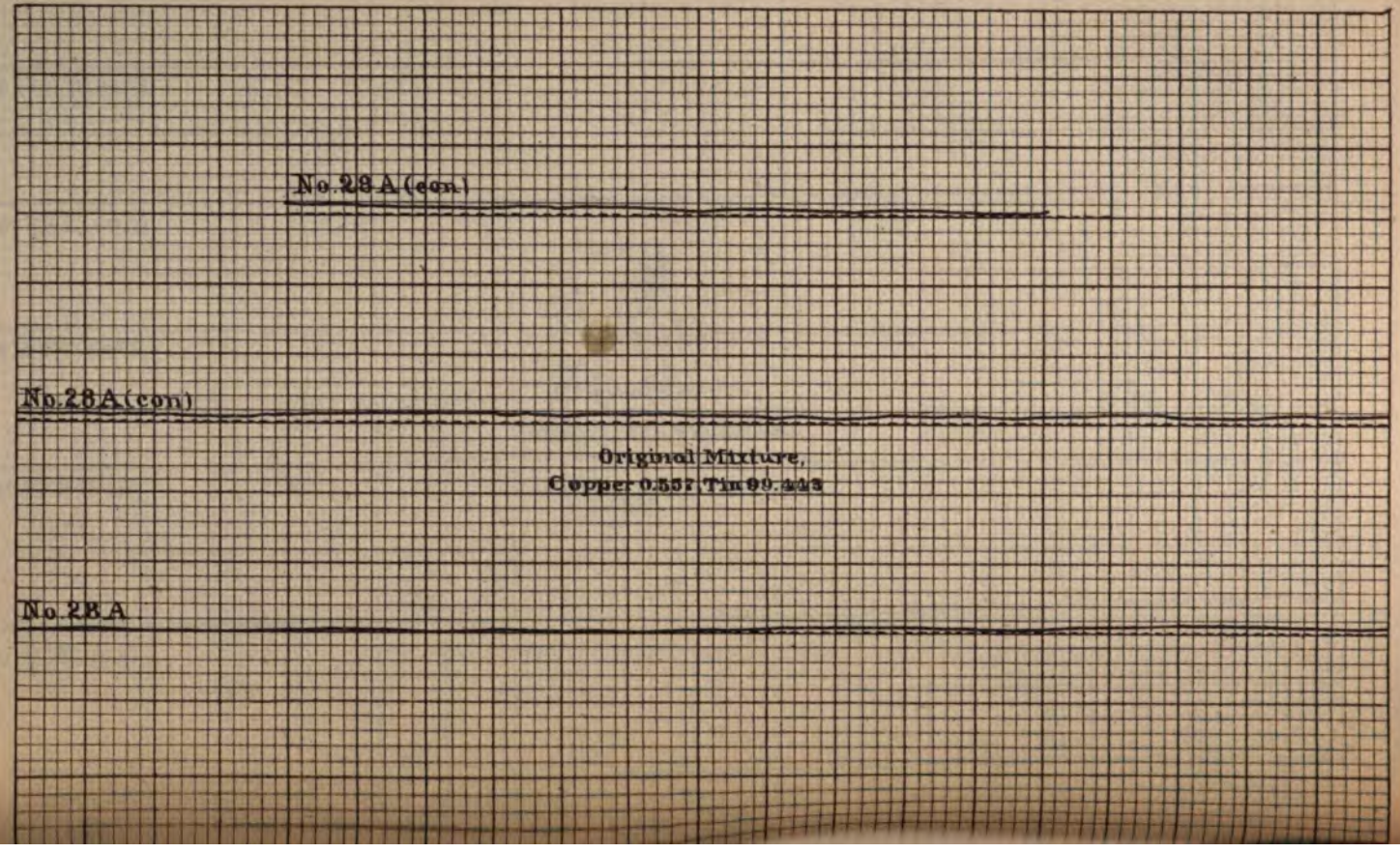
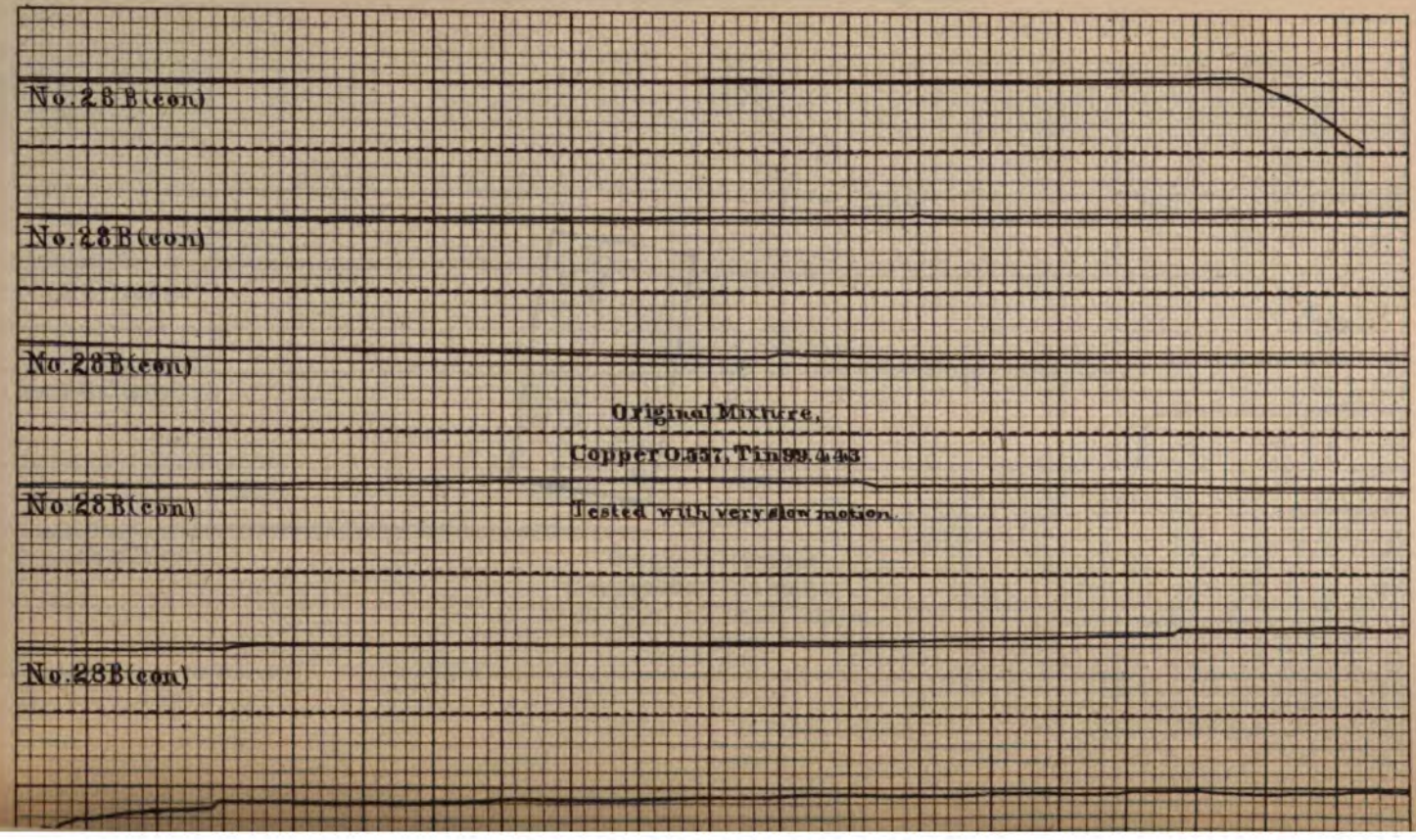


PLATE XLV.

Fac-Simile Autographic Strain Diagrams.



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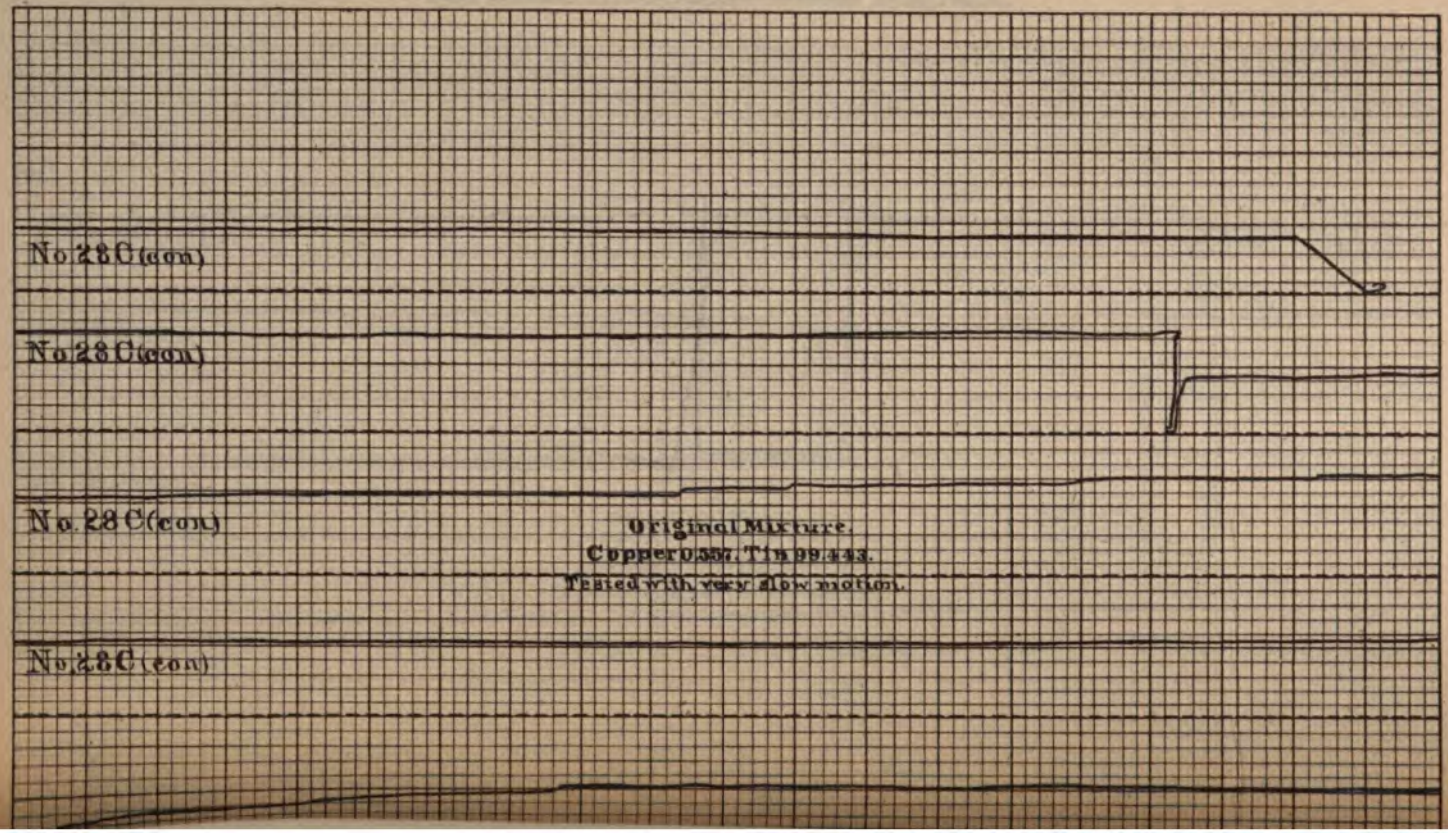
AND
TILDEN FOUNDATIONS

PLATE XLVI

Fac-Simile Autographic Strain Diagrams.



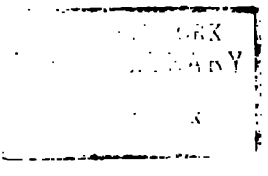


PLATE XLVII.

Fac-Simile Autographic Strain Diagrams.

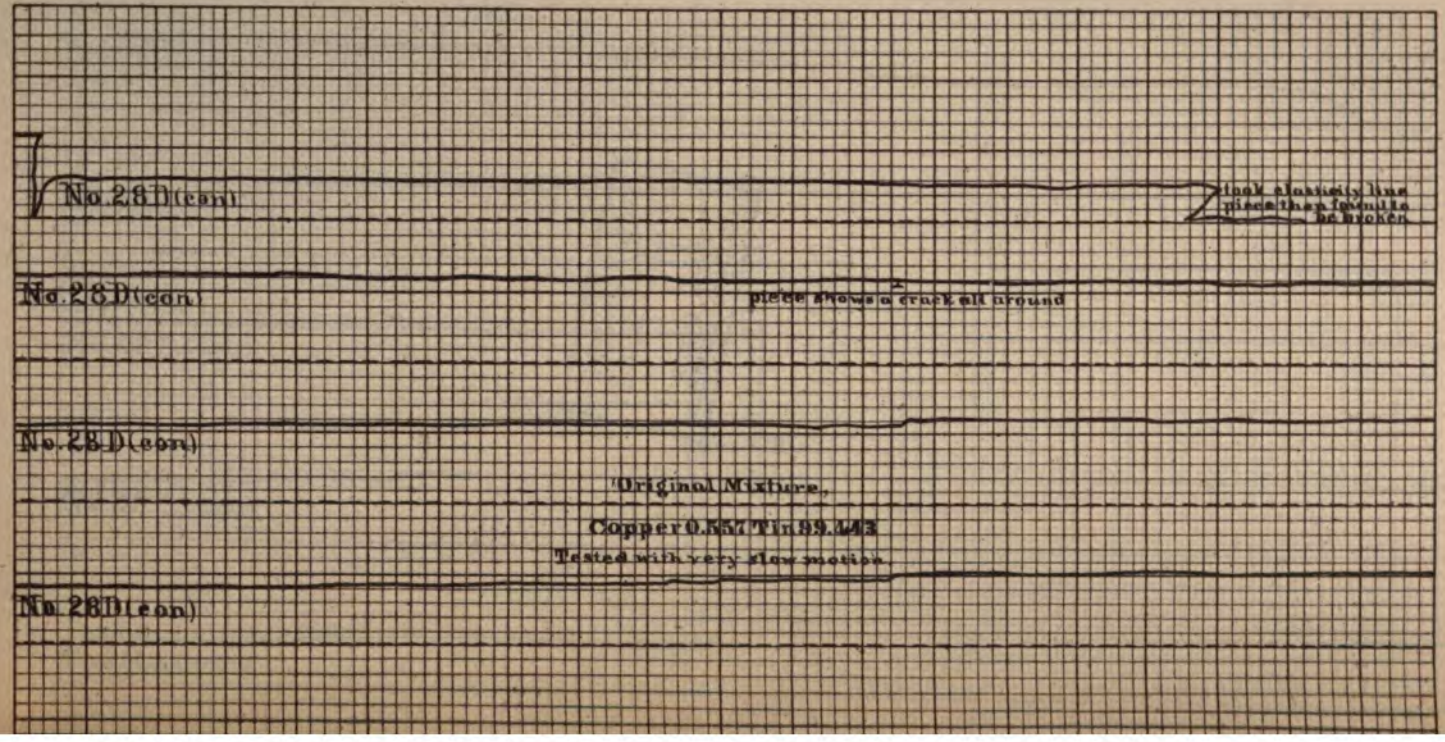

No. 28 D (con)
Last elasticity line piece that fe mit to be broken
No. 28 D (con)
piece shows a crack all around
No. 28 D (con)
Original Mixture.
Copper 0.557 Tin 99.443
Tested with very slow motion.
No. 28 D (con)

PLATE XLVIII.

Fac-Simile Autographic Strain Diagrams.

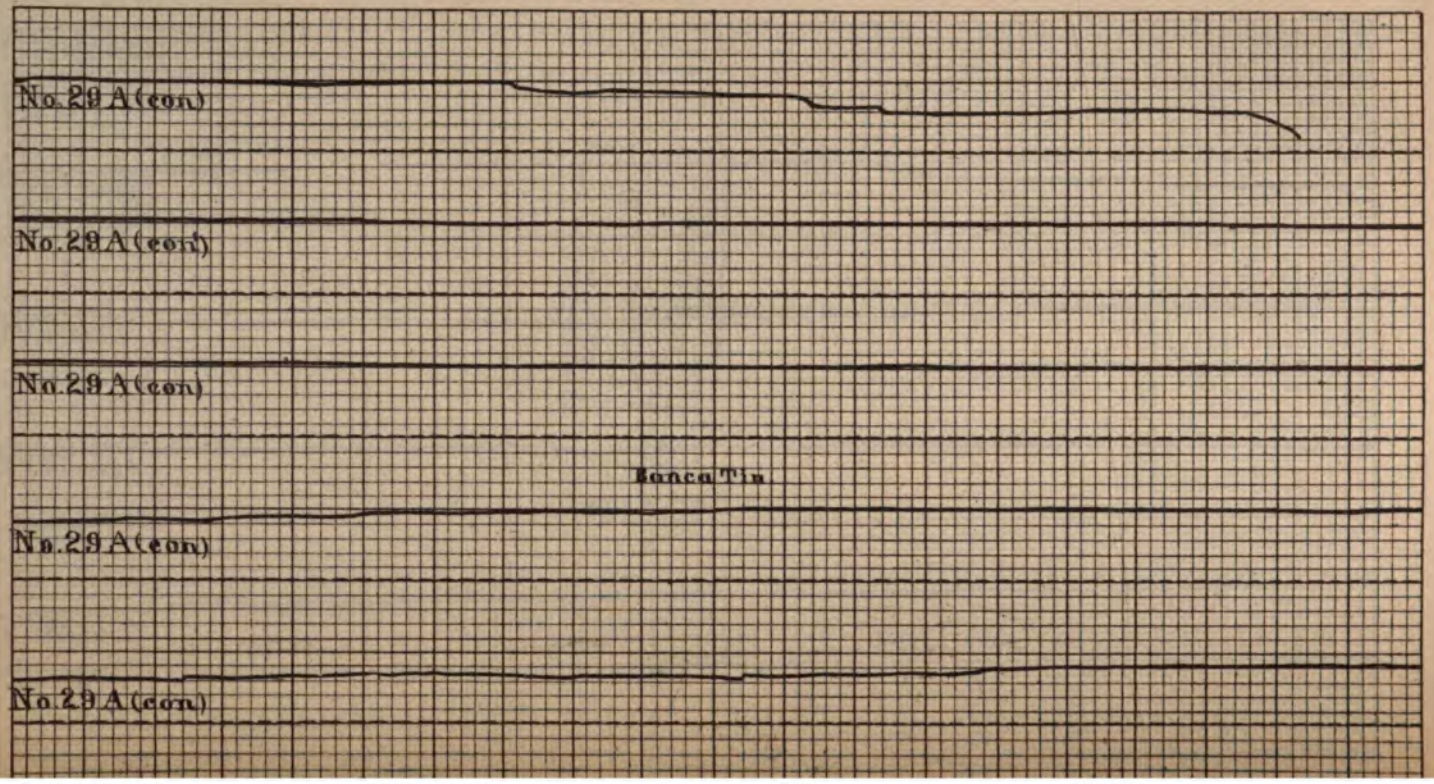


PLATE XLIX.

Fac-Simile Autographic Strain Diagrams.

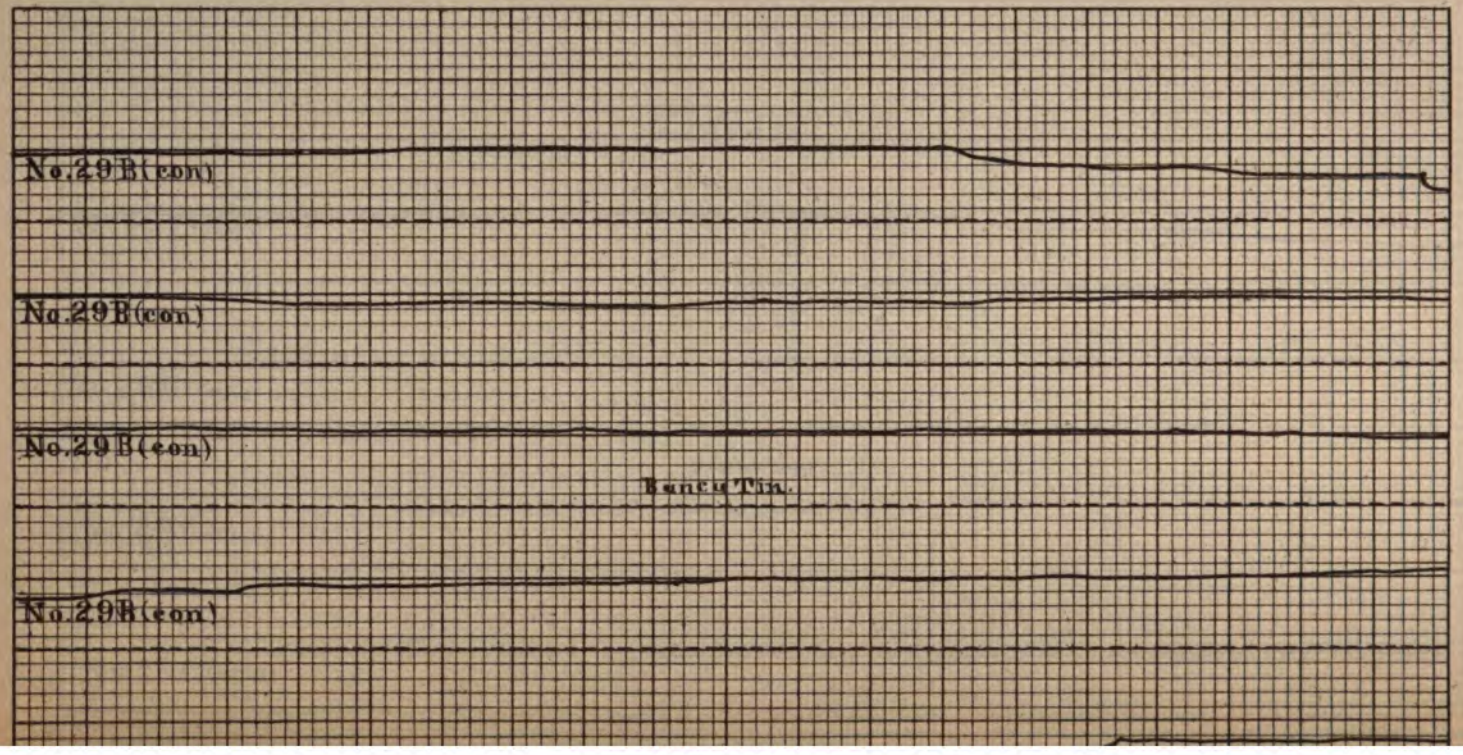


PLATE L.

Fac-Simile Autographic Strain Diagrams.

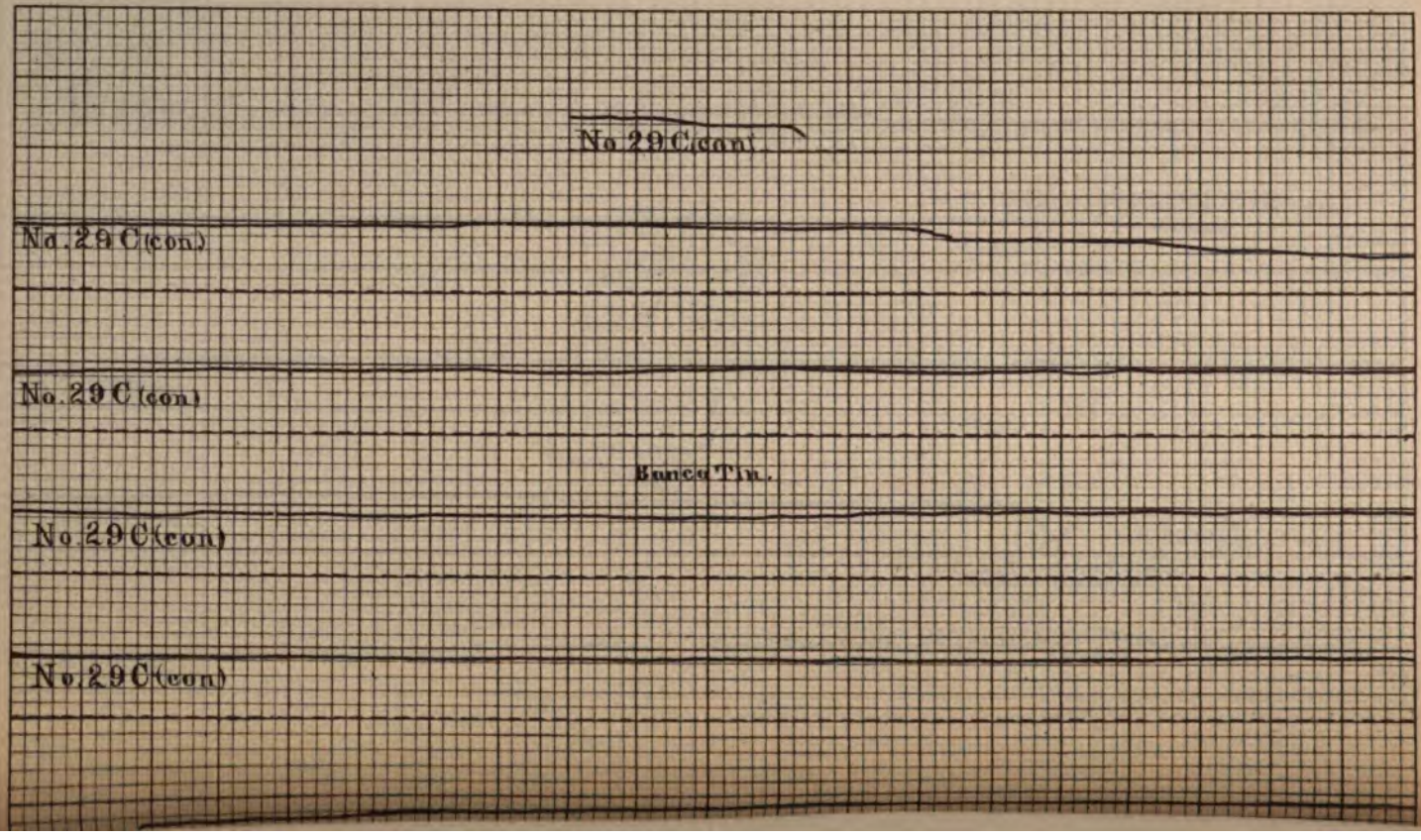
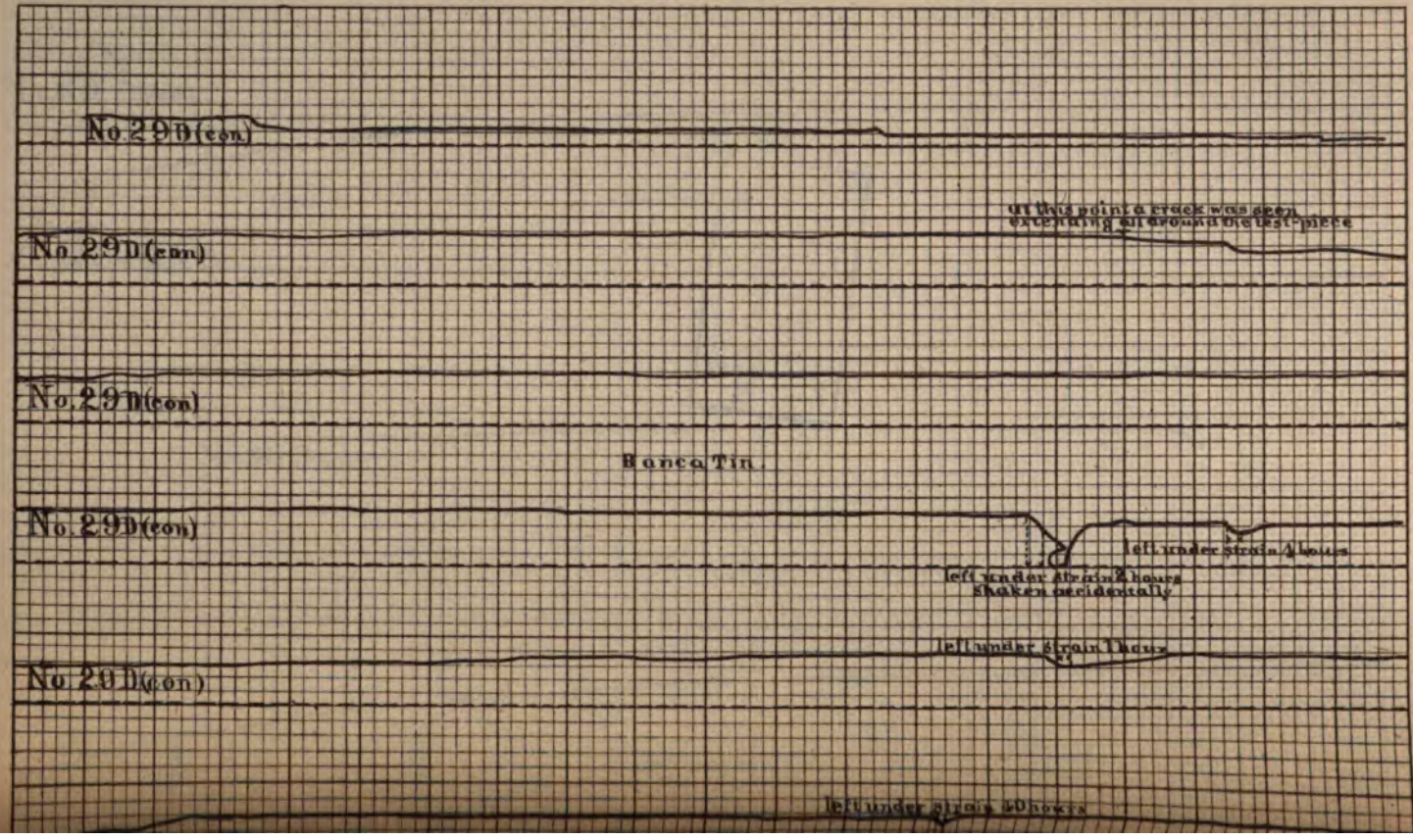


PLATE LI.

Fac-Simile Autographic Strain Diagrams.


No. 29D (con.)
At this point a crack was seen extending all around the test-piece
No. 29D (con.)
No. 29D (con.)
Banca Tin.
No. 29D (con.)
left under strain 4 hours
left under strain 2 hours shaken accidentally
left under strain 1 hour
No. 29D (con.)
left under strain 20 hours

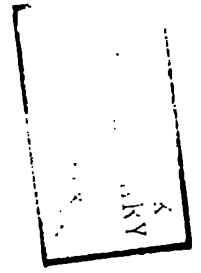
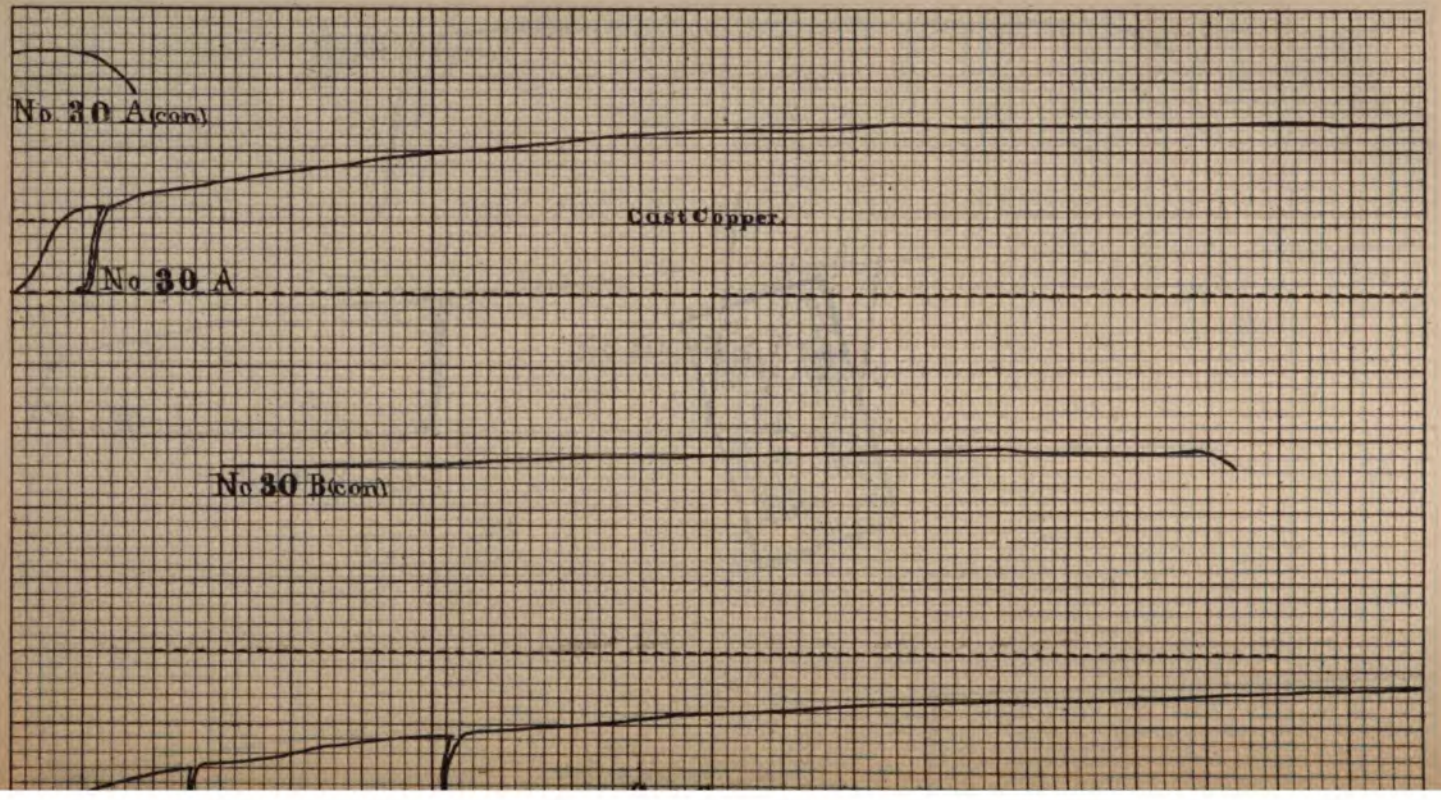


PLATE LII

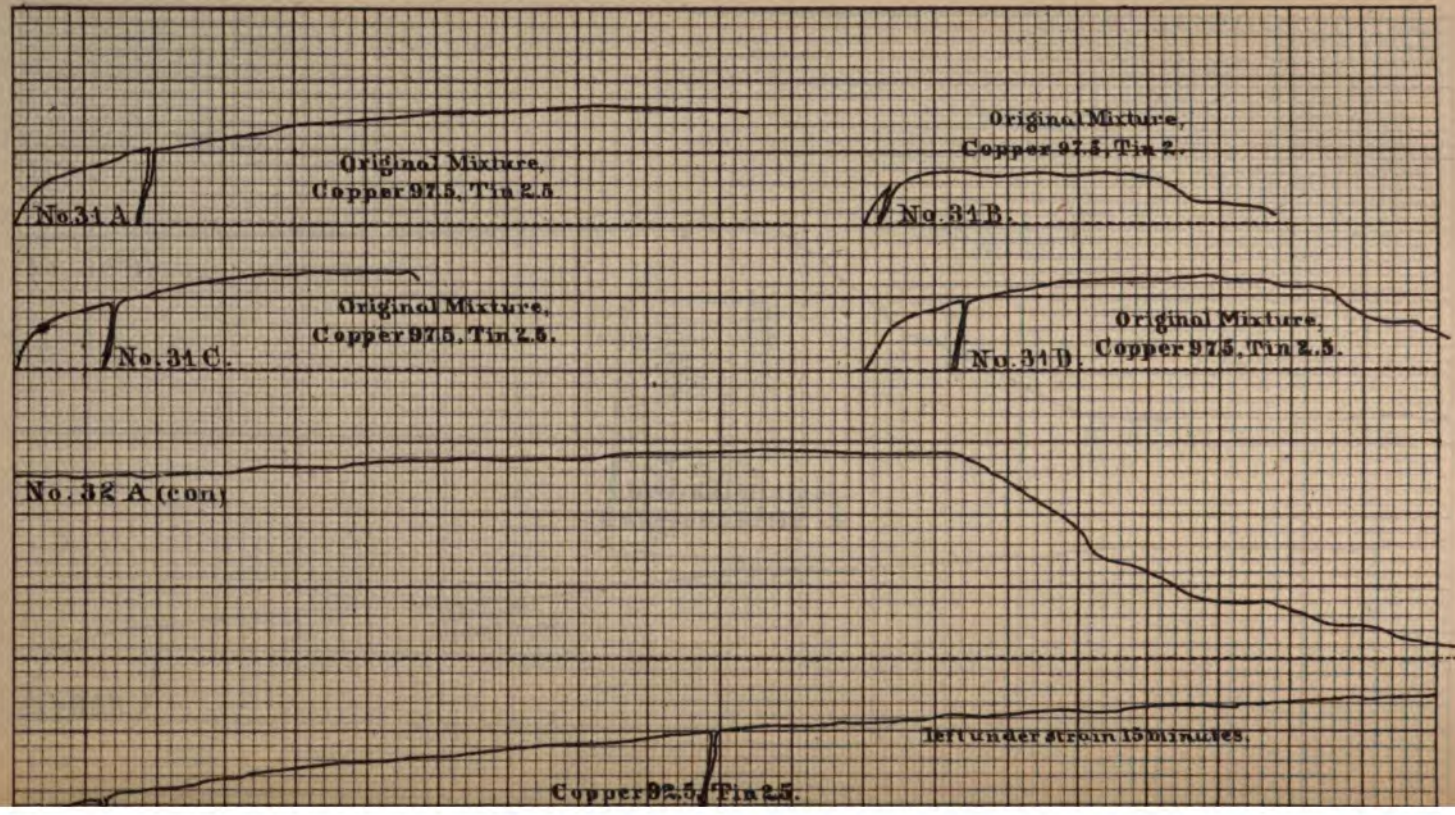
Fac-Simile Autographic Strain Diagrams.



LIBRARY

PLATE LIV.

Fac-Simile Autographic Strain Diagrams.



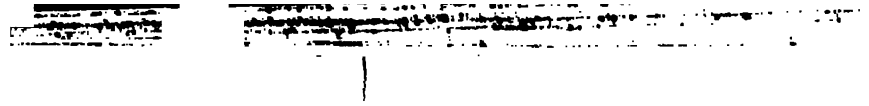


PLATE LV.

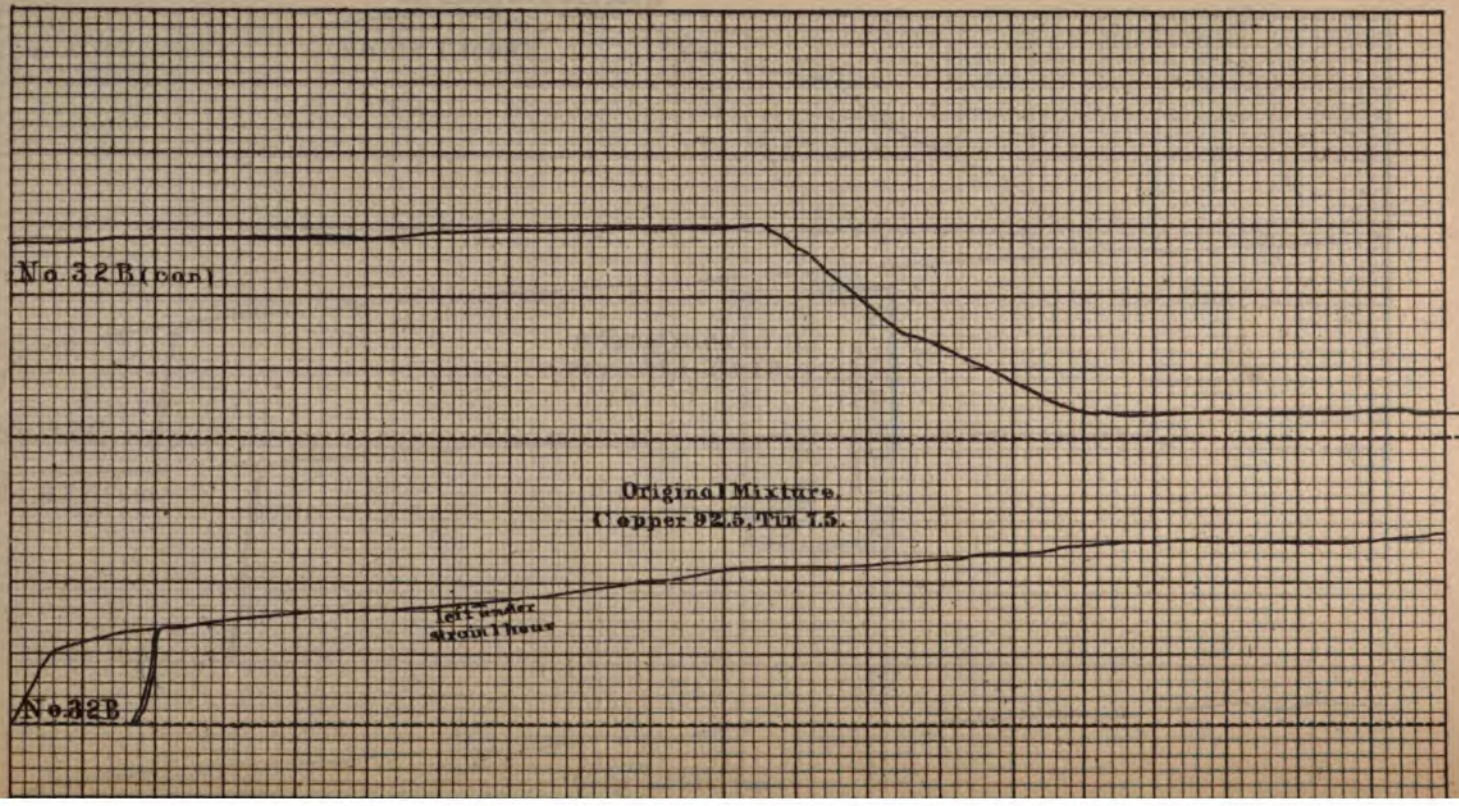

No. 32 B (con)
Original Mixture.
Copper 92.5, Tin 7.5.
left in Air
about 1 hour
No. 32 B

PLATE LVI.

Fac-Simile Autographic Strain Diagrams.

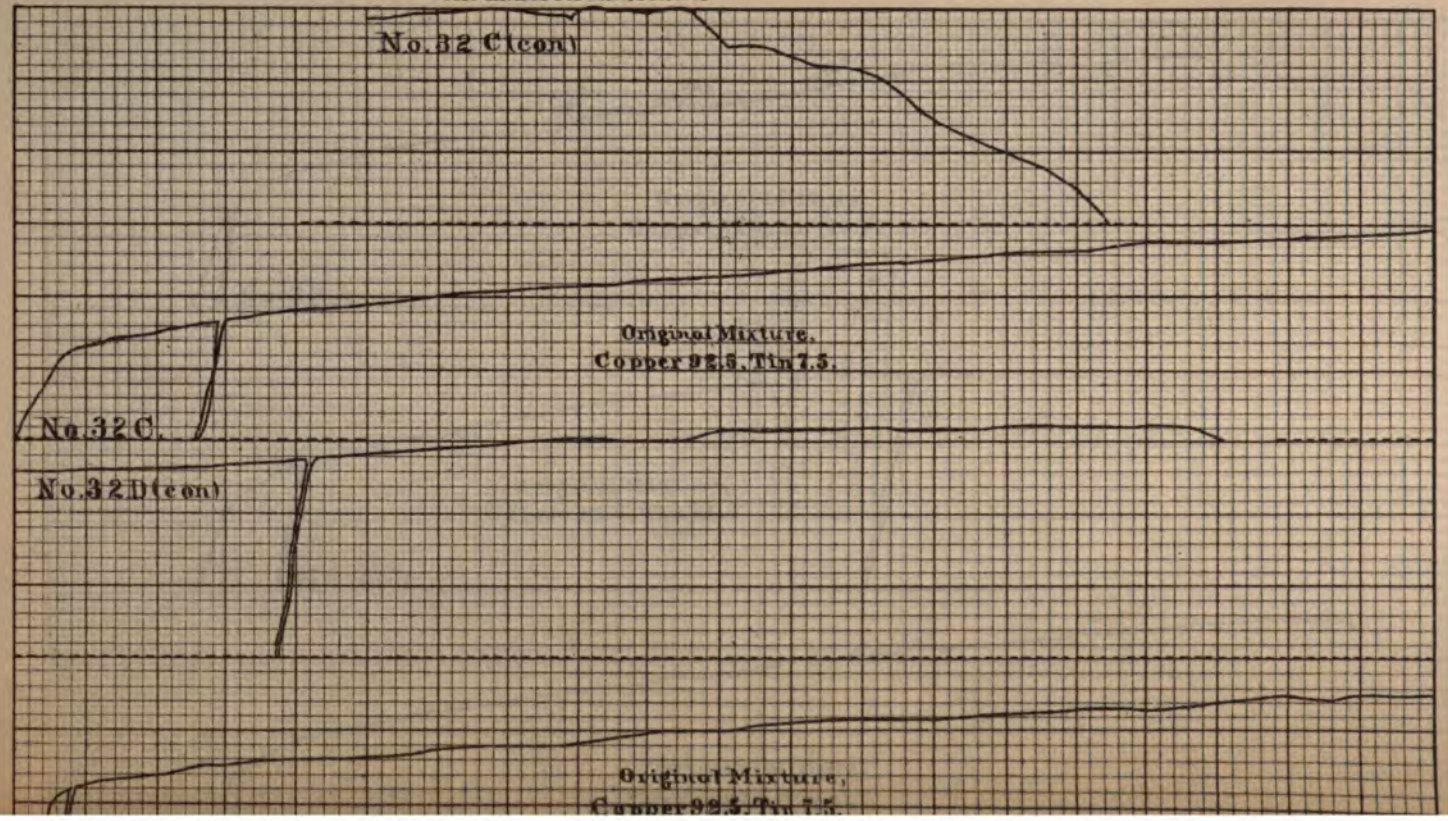


PLATE LVII.

Fac-Simile Autographic Strain Diagrams.

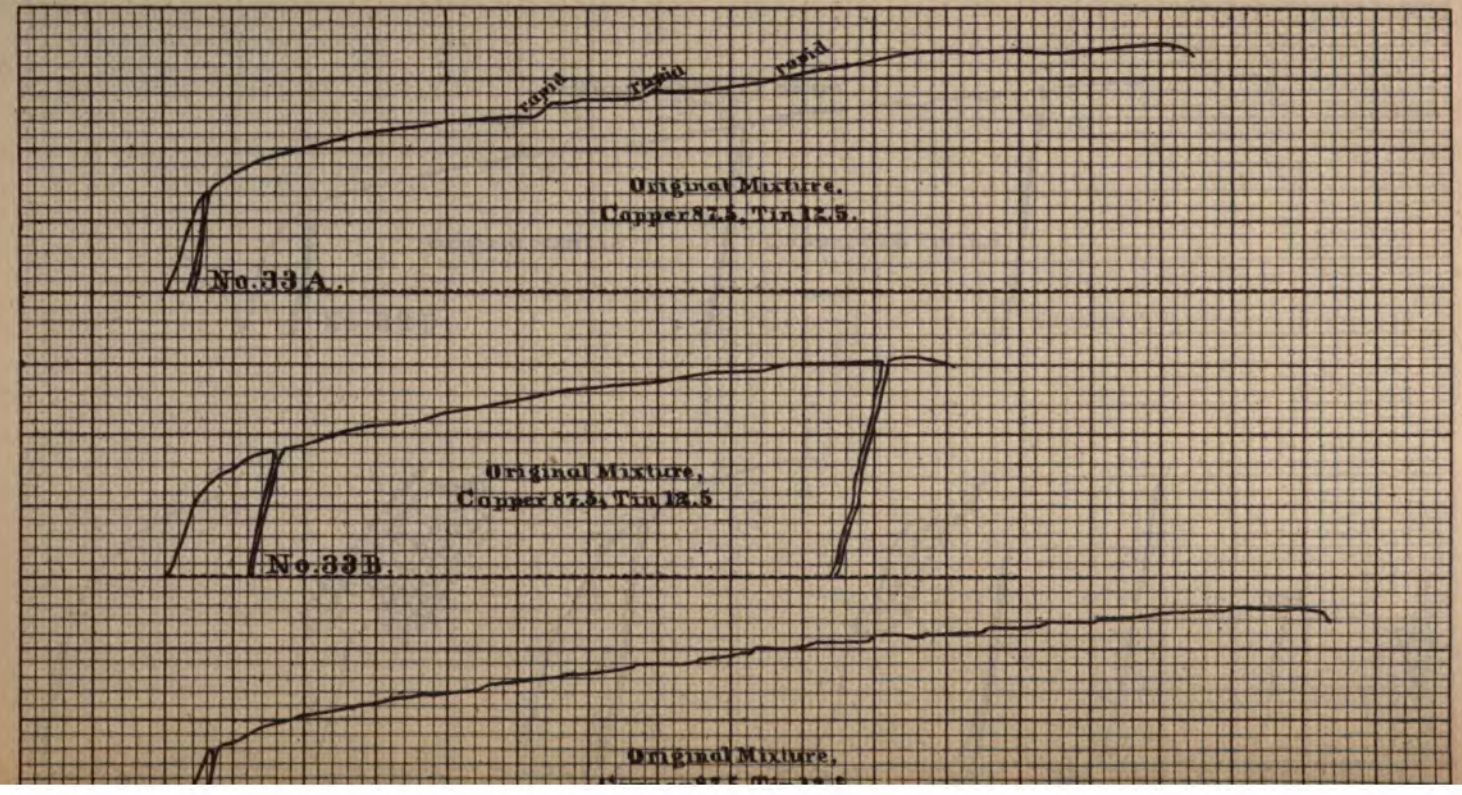
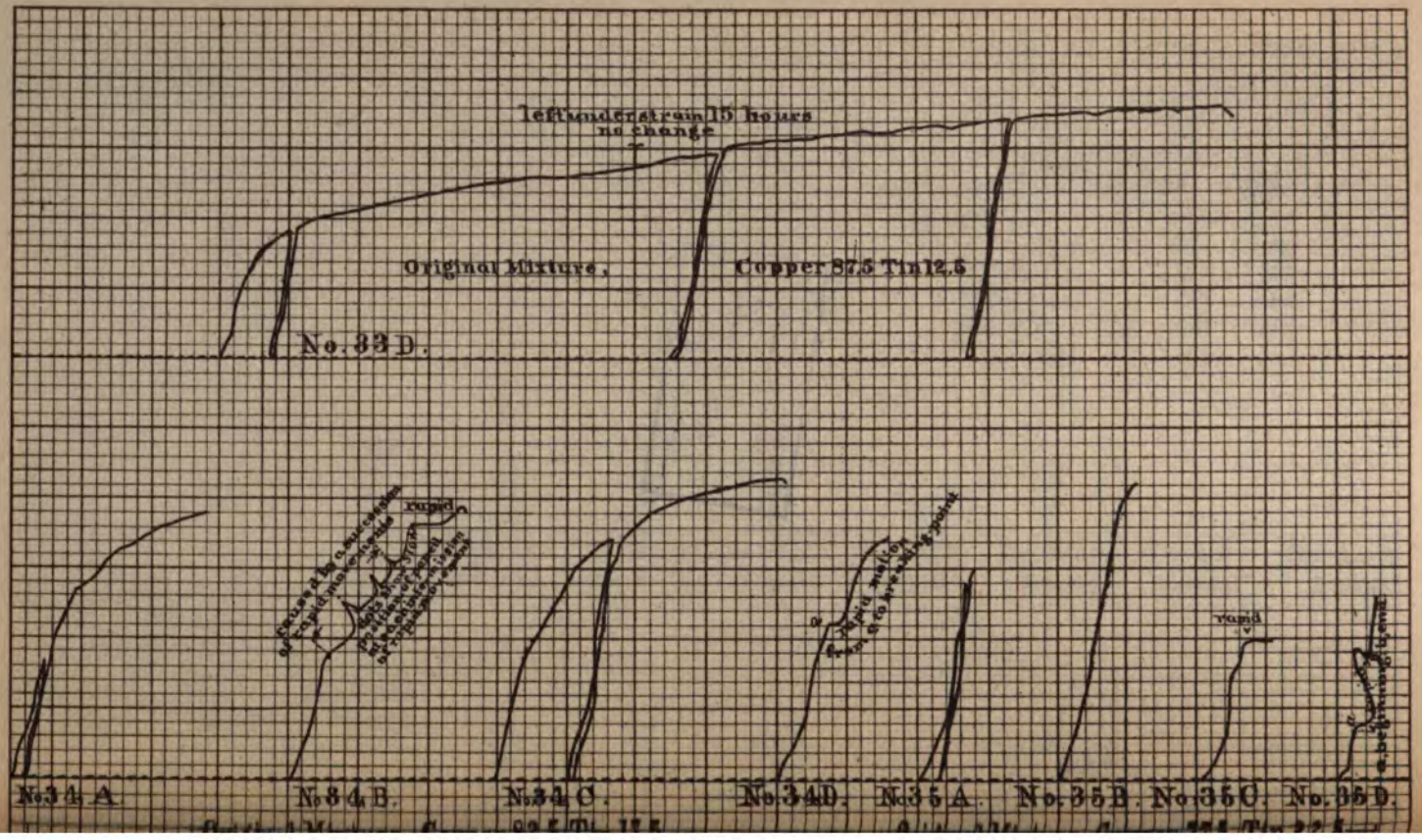


PLATE LVIII

Fac-Simile Autographic Strain Diagrams.



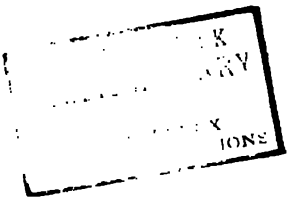
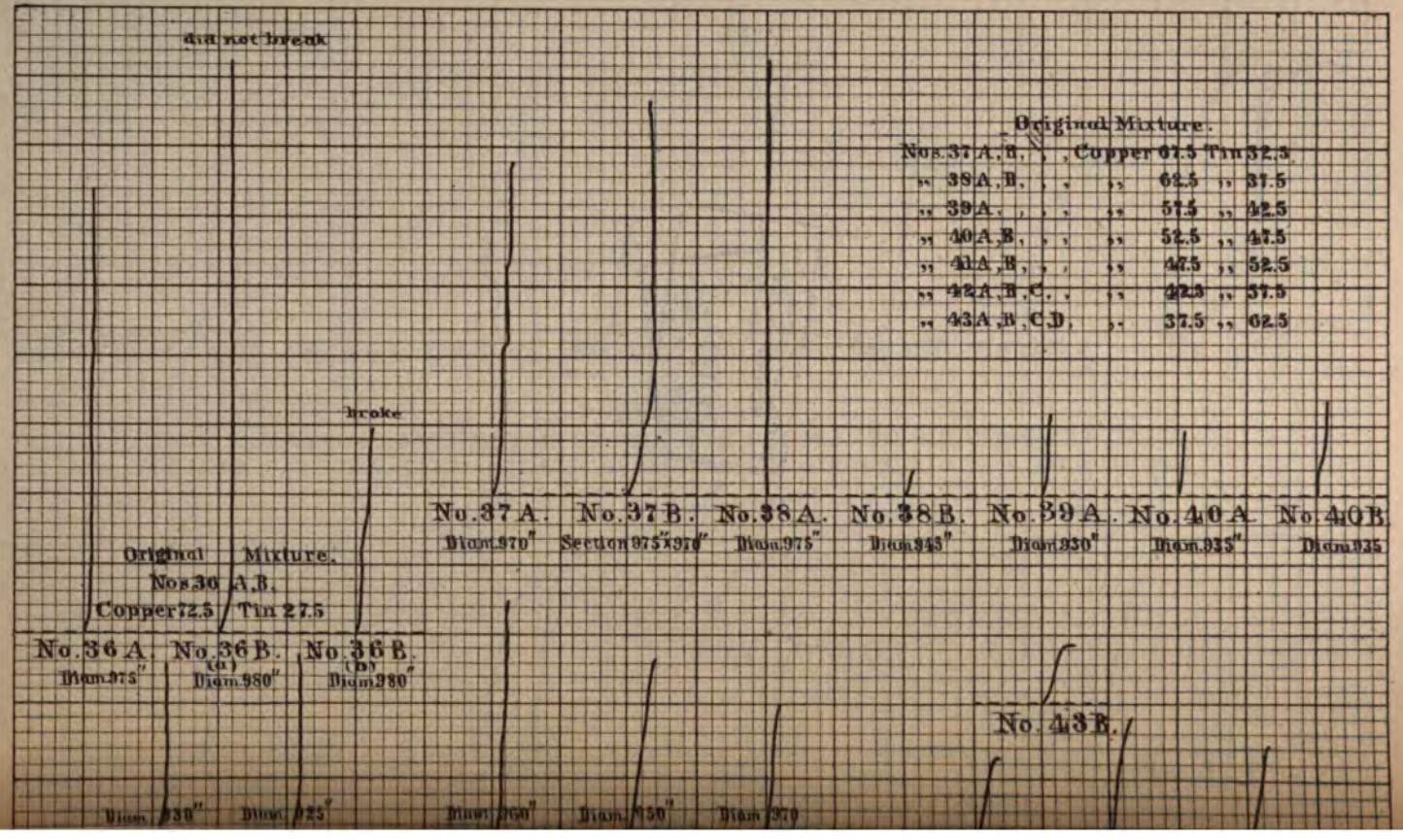


PLATE LIX.

Fac-Simile Autographic Strain Diagrams.



Original Mixture.

Nos. 37	A, B,	, ,	Copper	67.5	Tin 32.5
,, 38	A, B,	, ,	,,	62.5	,, 37.5
,, 39	A, ,	, ,	,,	57.5	,, 42.5
,, 40	A, B,	, ,	,,	52.5	,, 47.5
,, 41	A, B,	, ,	,,	47.5	,, 52.5
,, 42	A, B, C,	, ,	,,	42.5	,, 57.5
,, 43	A, B, C, D,	, ,	,,	37.5	,, 62.5

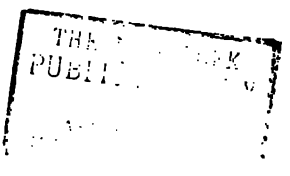

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PLATE LX.

Fac-Simile Autographic Strain Diagrams.

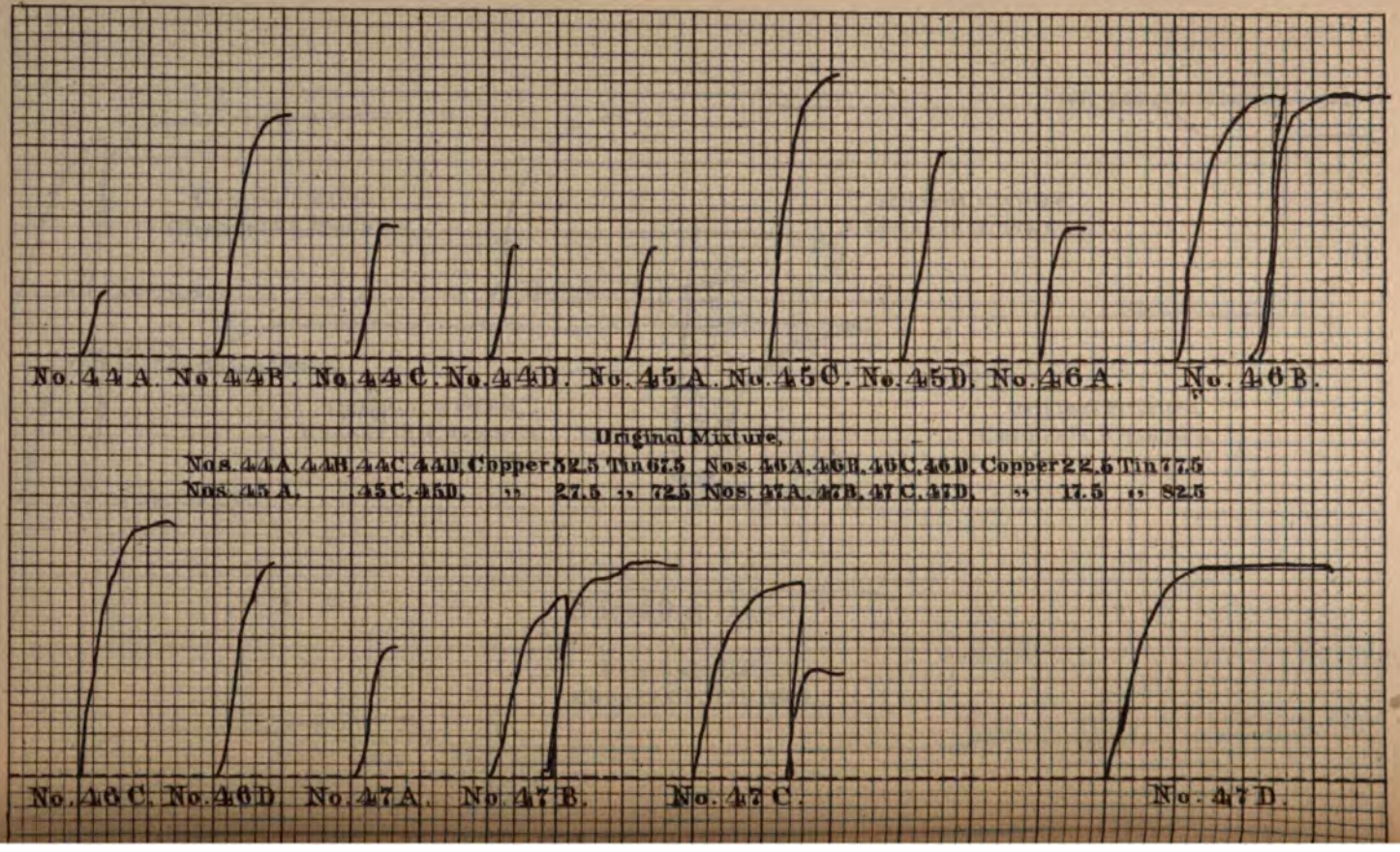
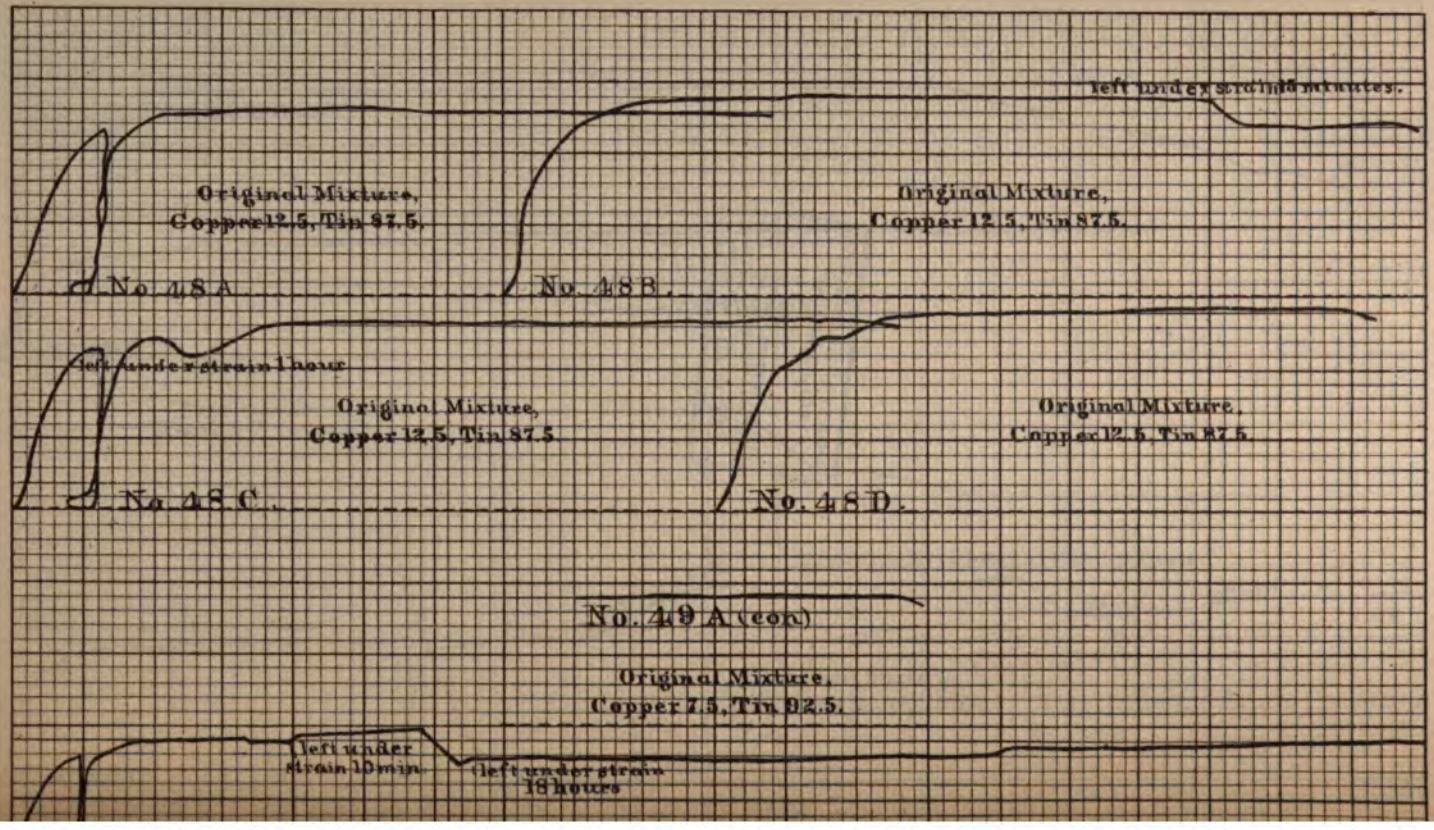

No. 44 A.
No. 44 B.
No. 44 C.
No. 44 D.
No. 45 A.
No. 45 C.
No. 45 D.
No. 46 A.
No. 46 B.
Original Mixture.
Nos. 44 A, 44 B, 44 C, 44 D, Copper 52.5 Tin 47.5
Nos. 45 A, 45 C, 45 D, ,, 27.5 ,, 72.5
Nos. 46 A, 46 B, 46 C, 46 D, Copper 22.5 Tin 77.5
Nos. 47 A, 47 B, 47 C, 47 D, ,, 17.5 ,, 82.5
No. 46 C.
No. 46 D.
No. 47 A.
No. 47 B.
No. 47 C.
No. 47 D.

PLATE LXI.

Fac-Simile Autographic Strain Diagrams.



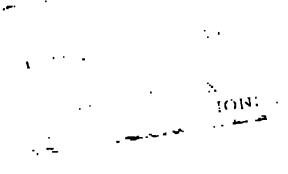


PLATE LXII

Fac-Simile Autographic Strain Diagrams.

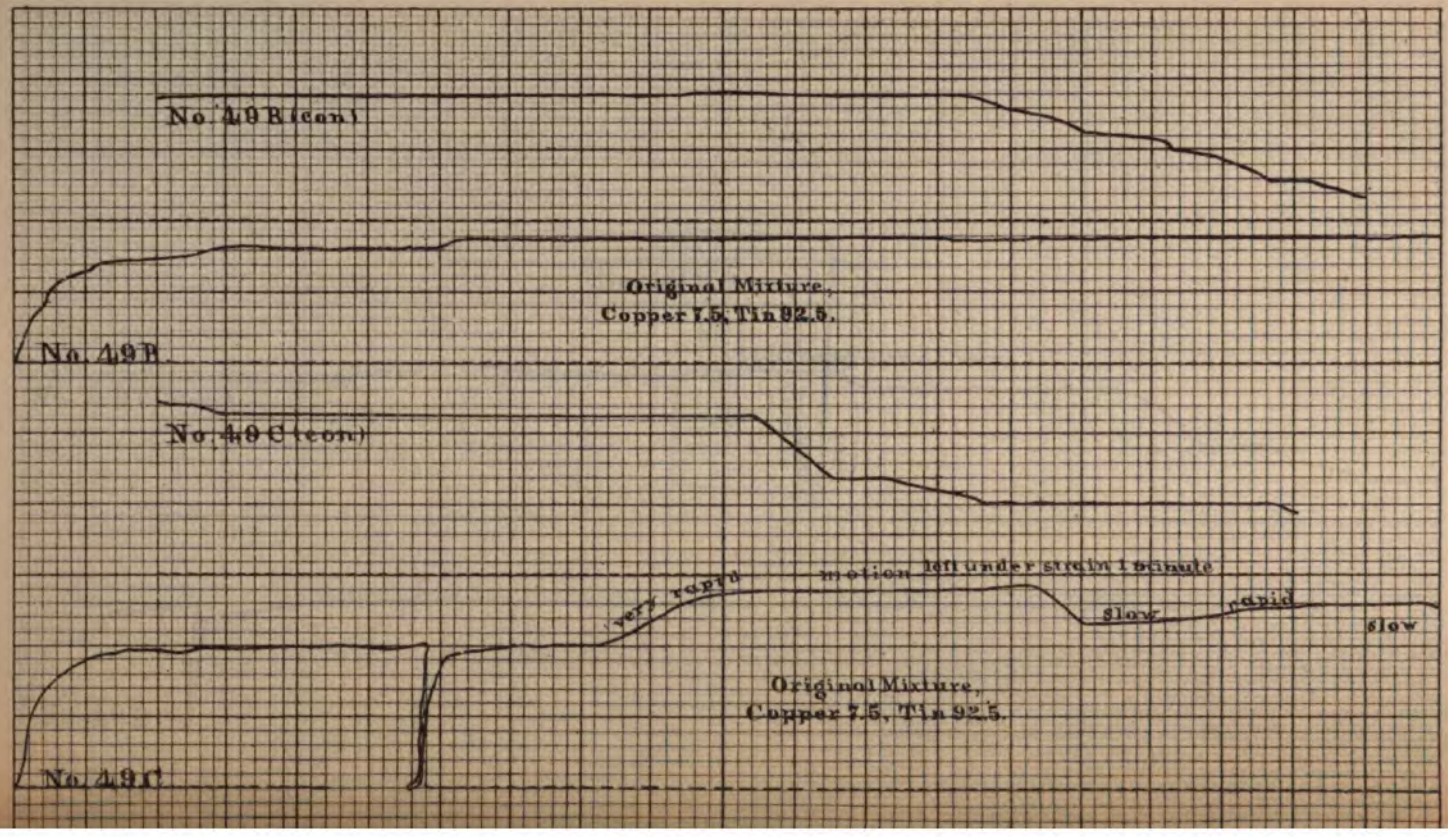


PLATE LXIII.

Fac-Simile Autographic Strain Diagrams.

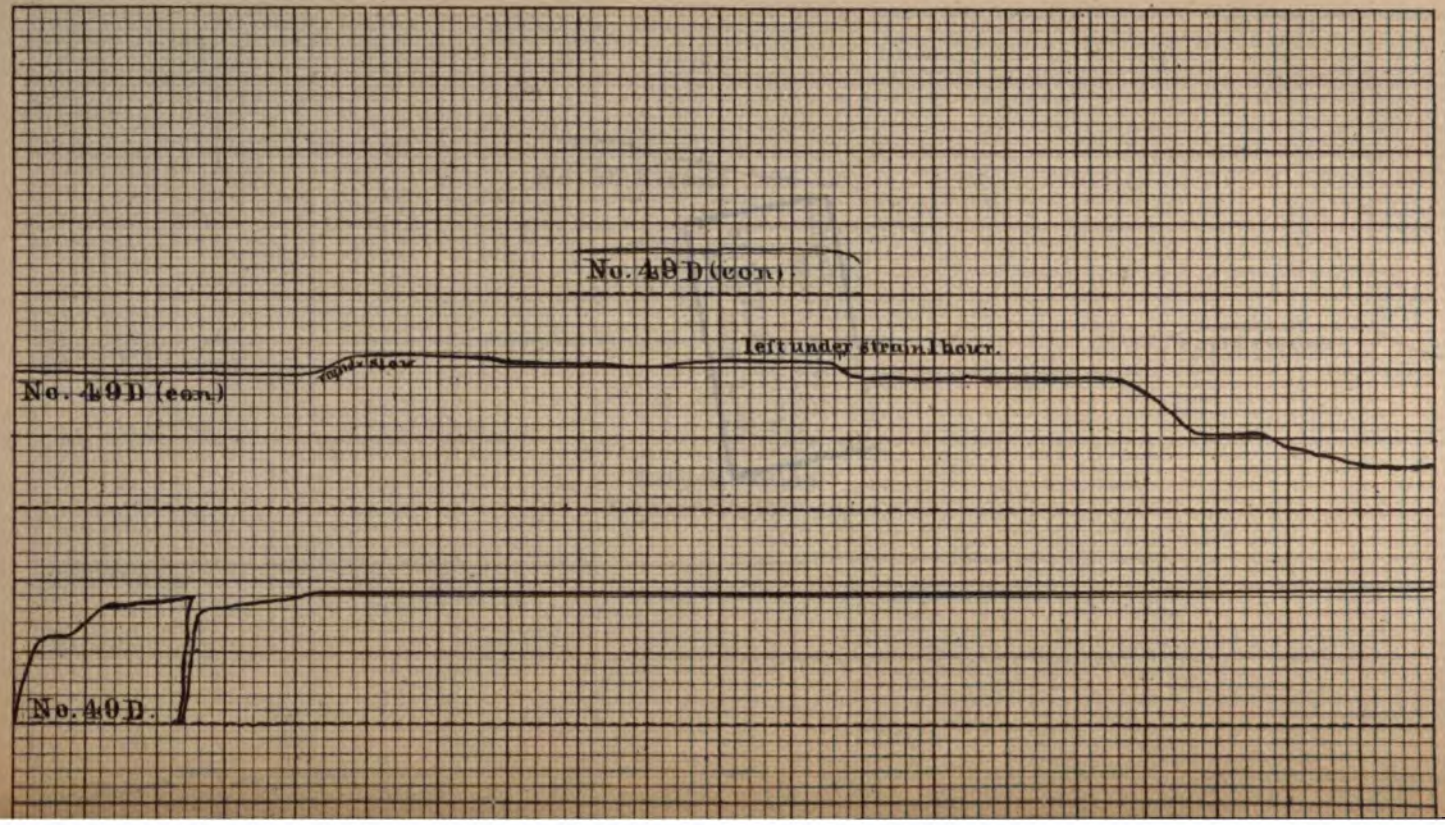


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PLATE LXIV.

Fac-Simile Autographic Strain Diagrams.

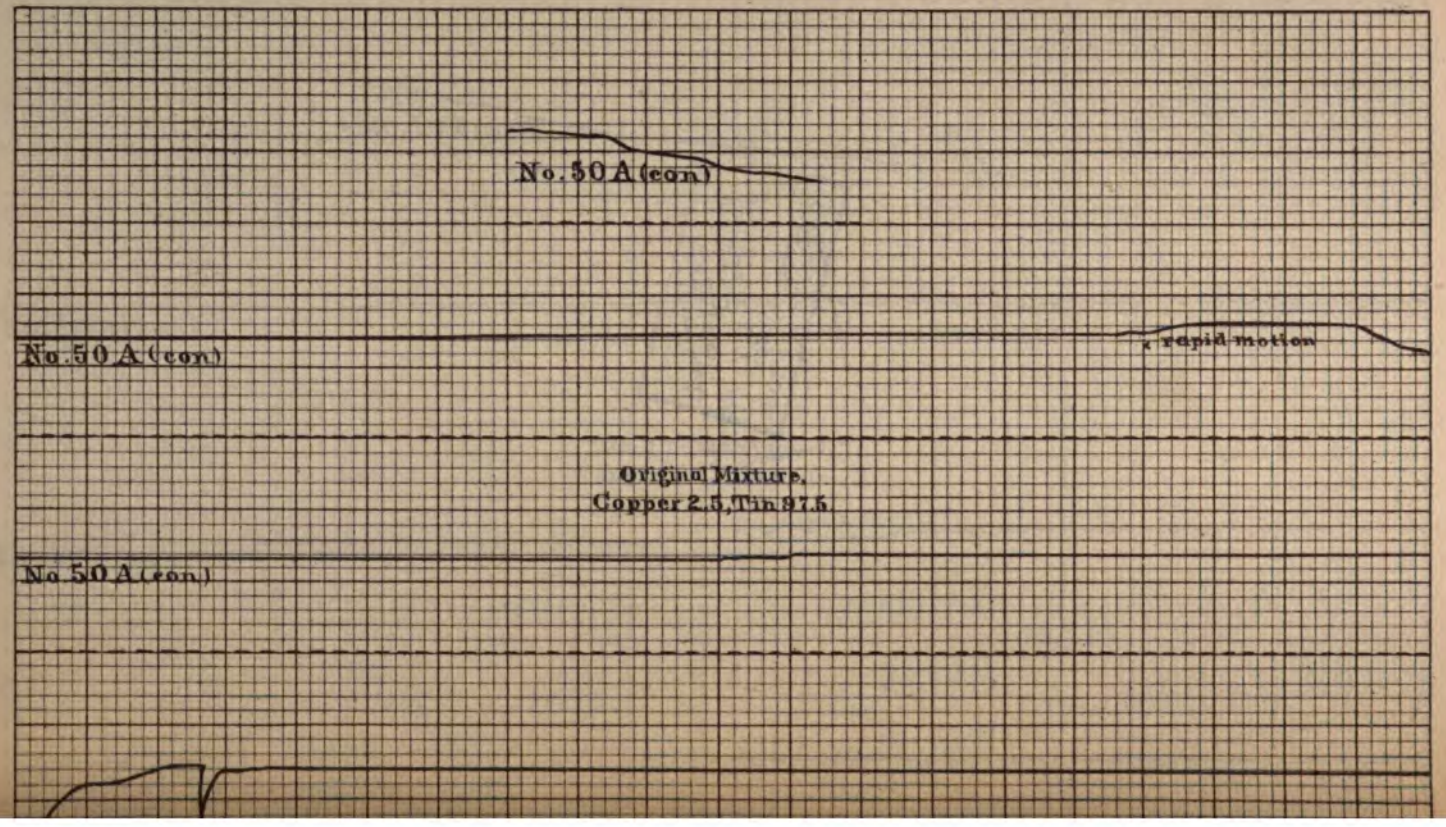
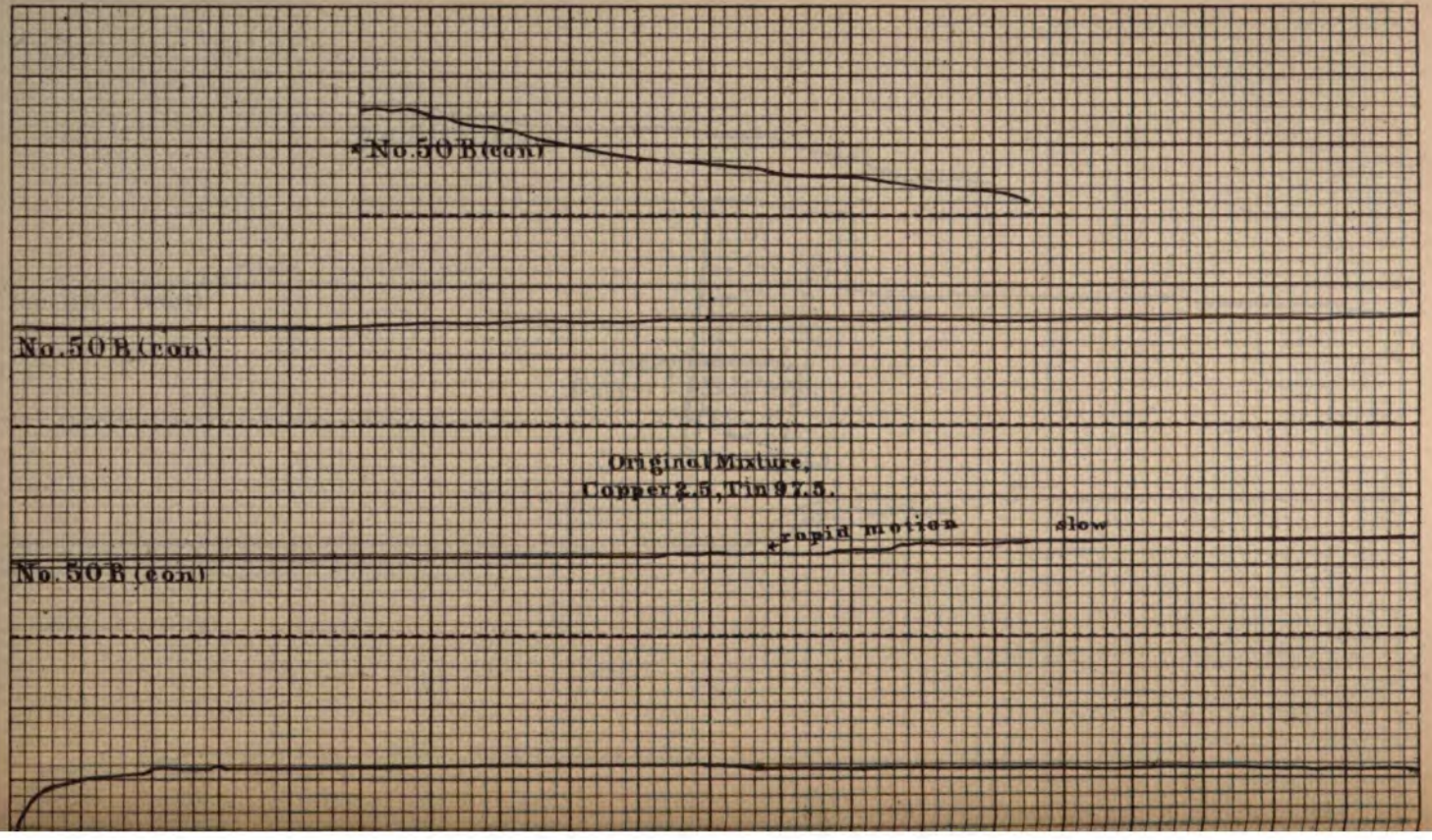


PLATE LXV.

Fac-Simile Autographic Strain Diagrams.



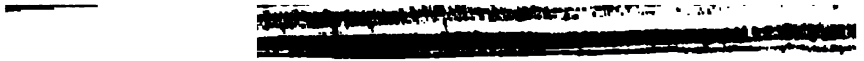
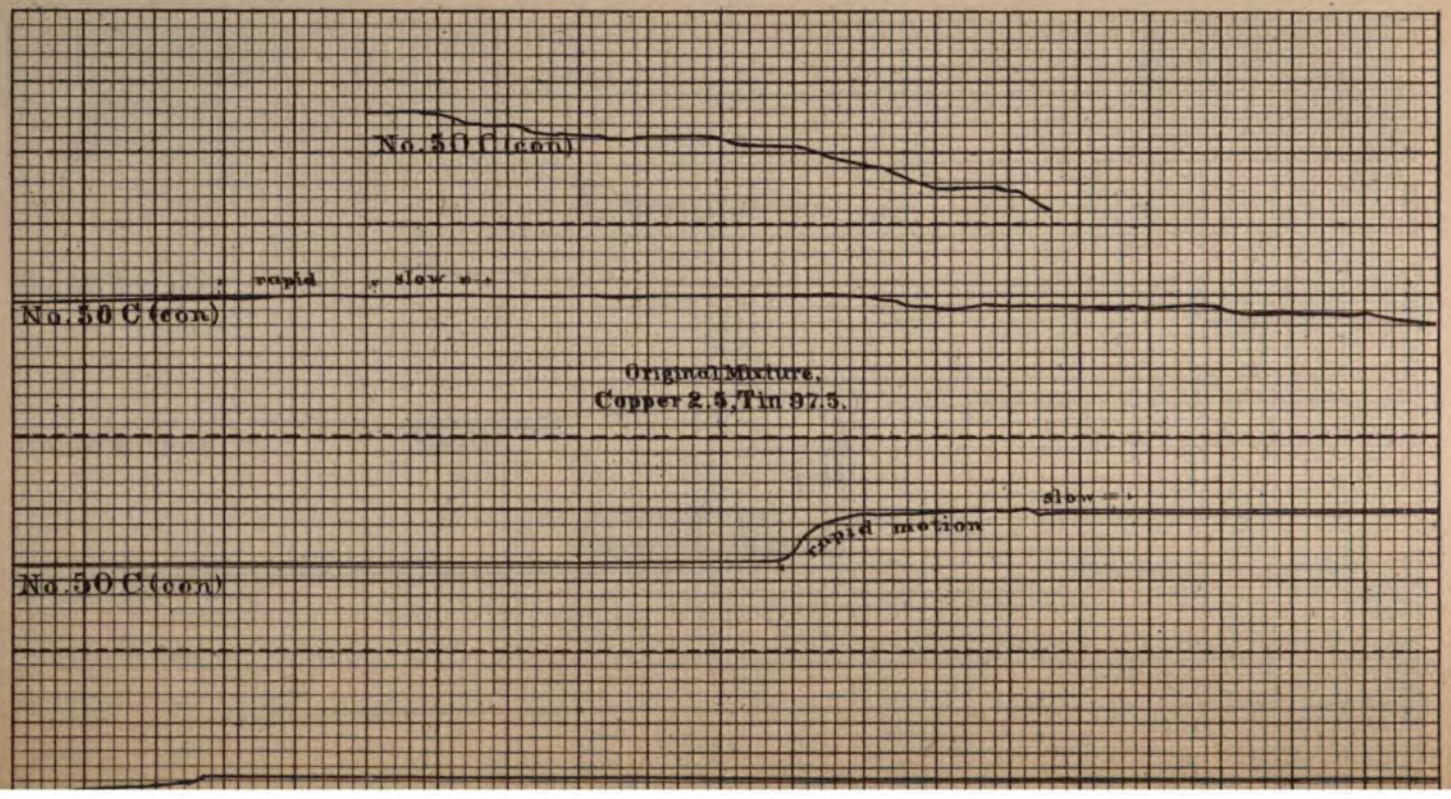


PLATE LXVI

Fac-Simile Autographic Strain Diagrams.



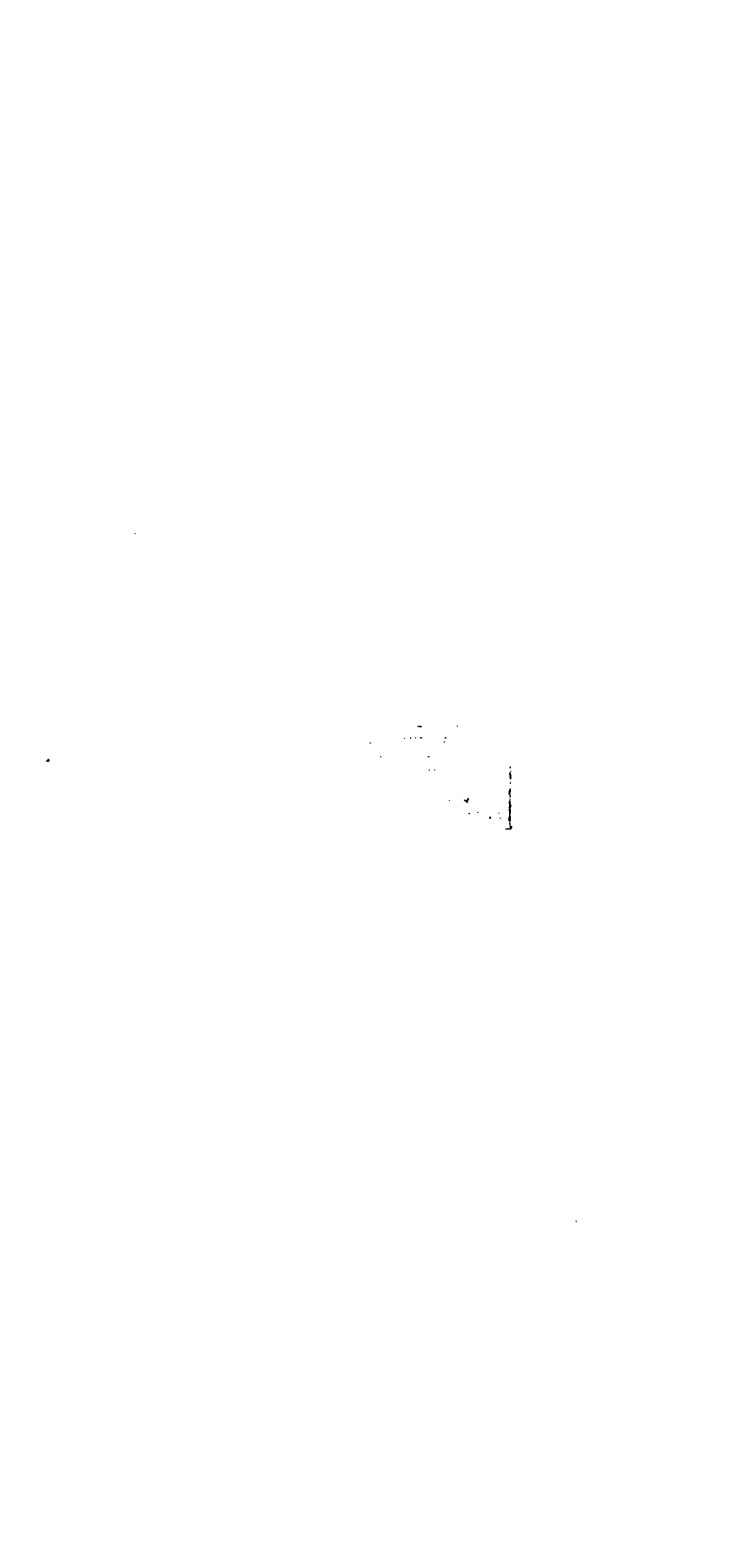
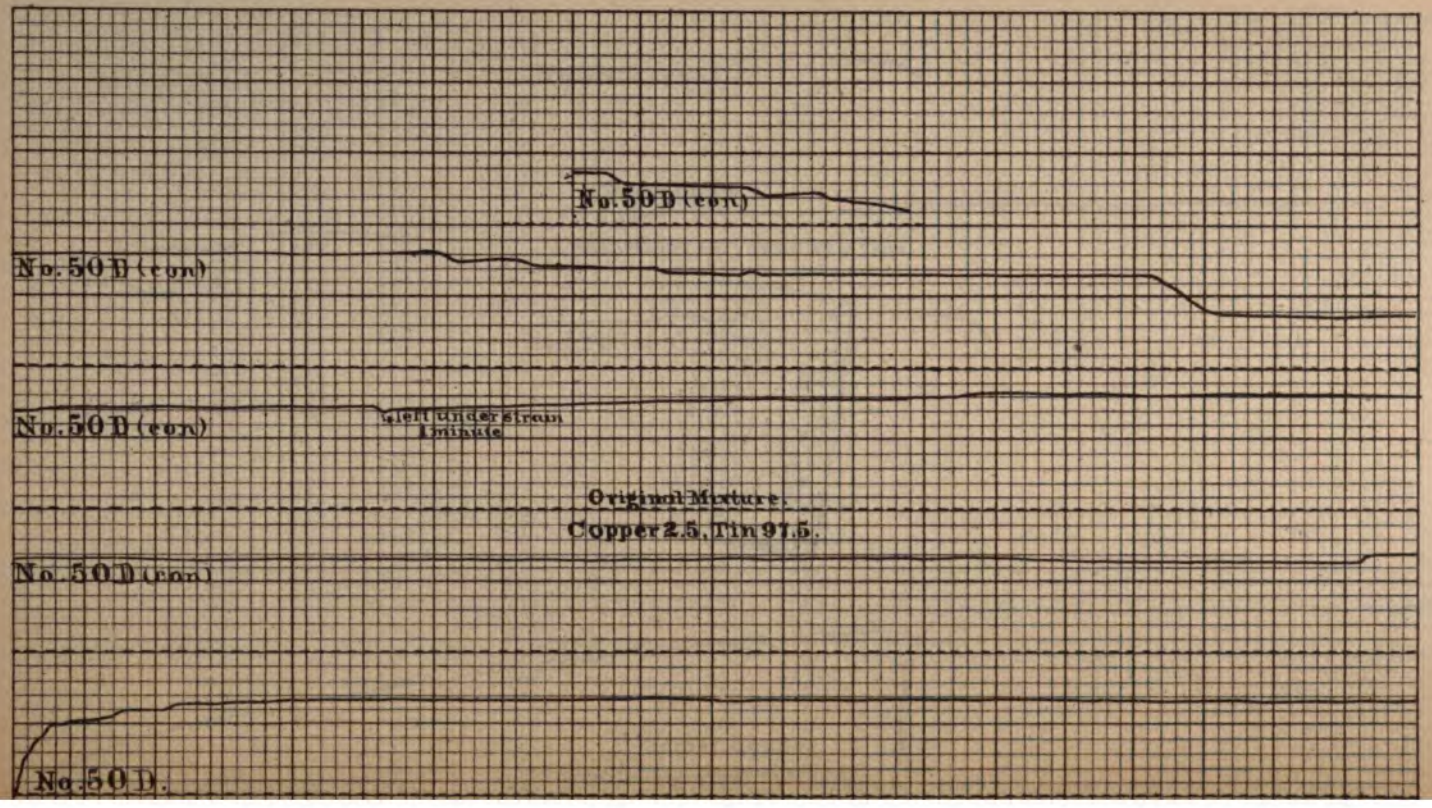


PLATE LXVII.

Fac-Simile Autographic Strain Diagrams.



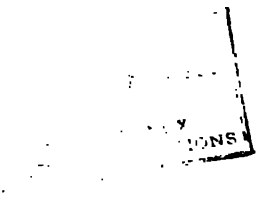


PLATE LXVIII.

Fac-Simile Autographic Strain Diagrams.

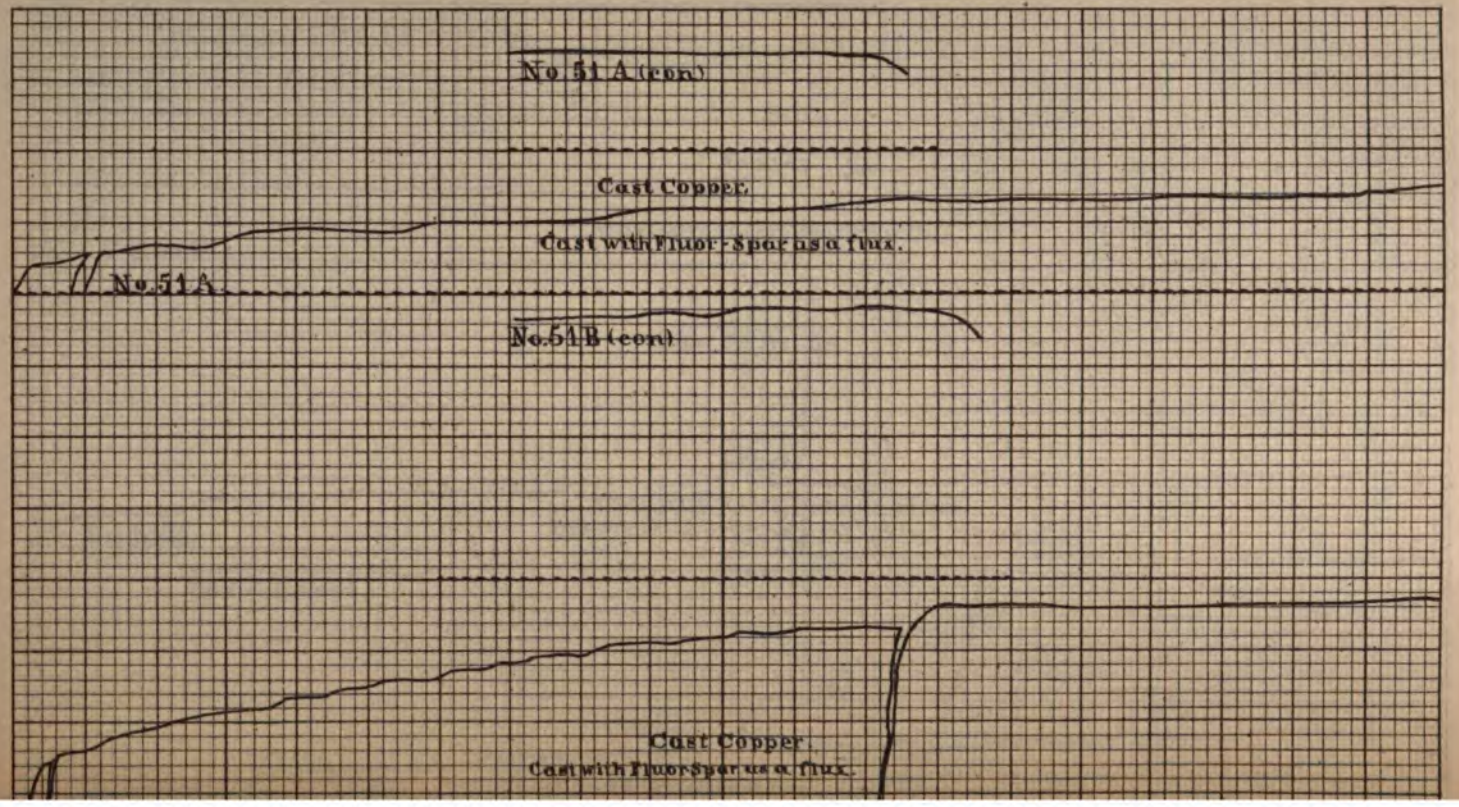
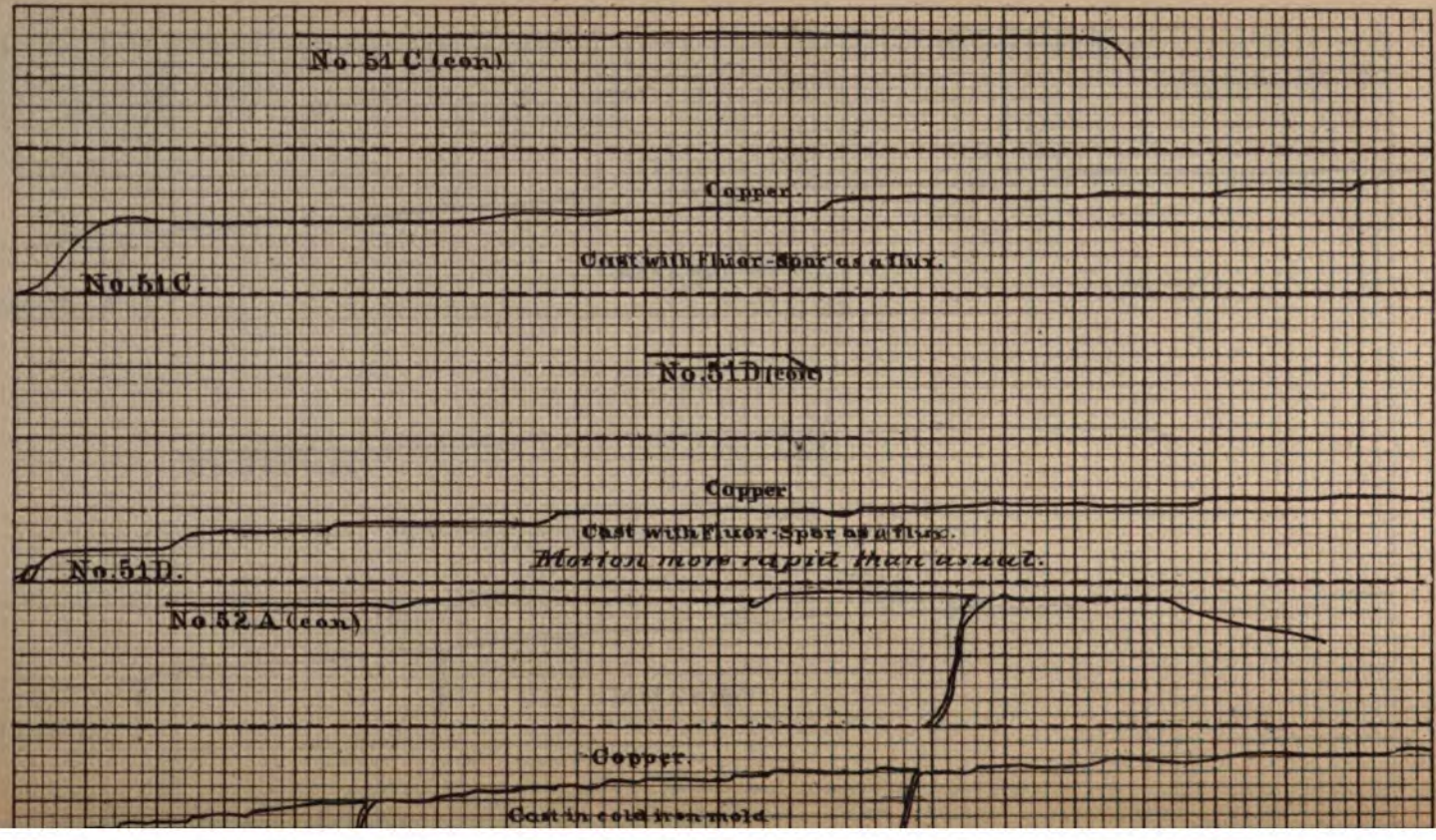


PLATE LXIX.

Fac-Simile Autographic Strain Diagrams.



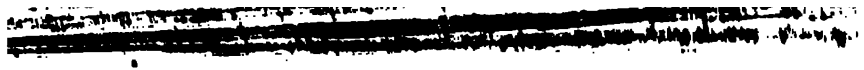
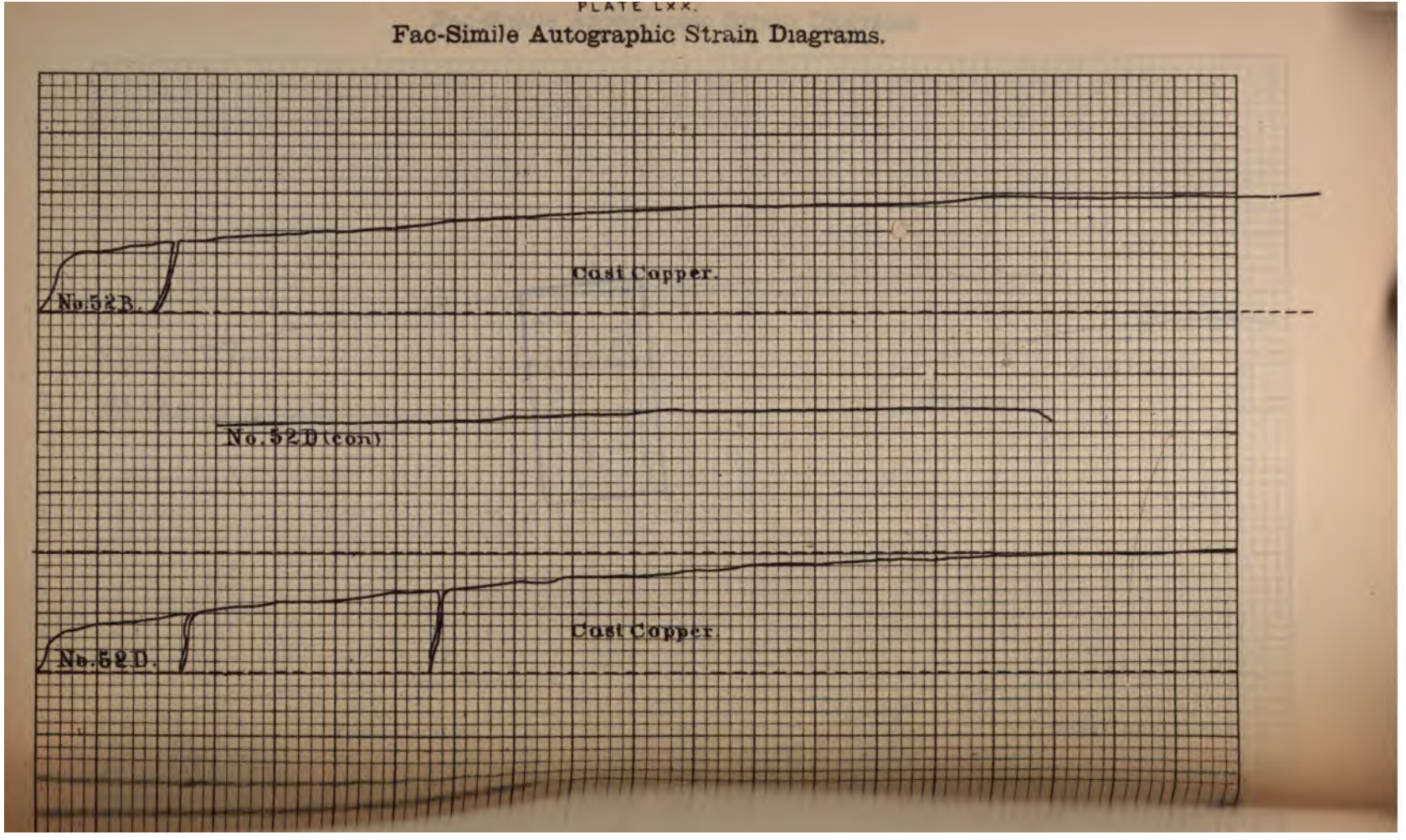


PLATE LXX.

Fac-Simile Autographic Strain Diagrams.



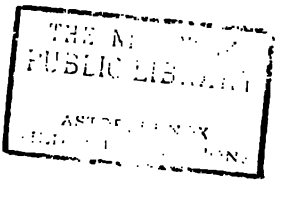

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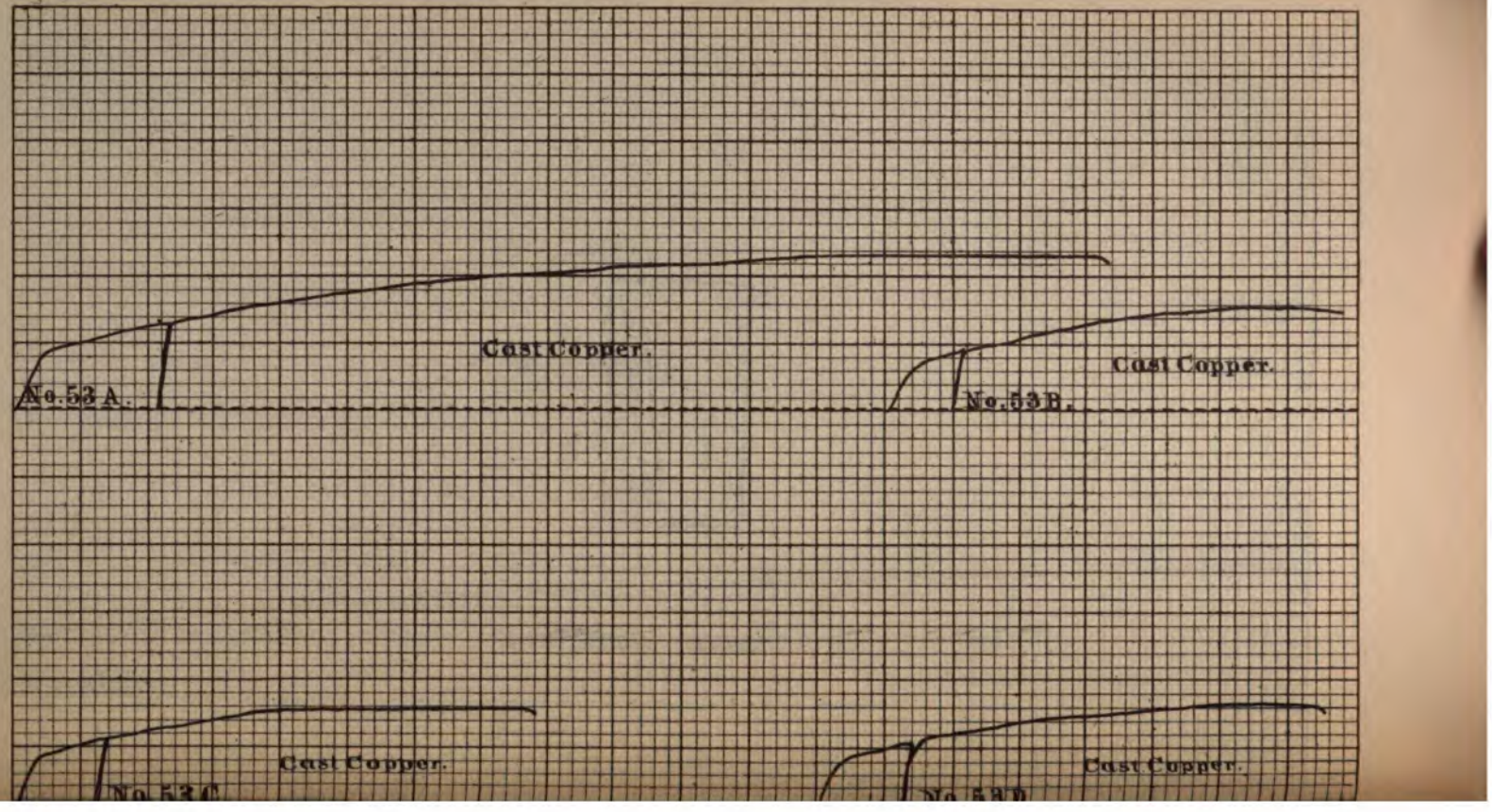
PLATE LXXI.

Fac-Simile Autographic Strain Diagrams.



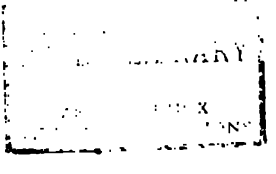


PLATE LXXII.

Fac-Simile Autographic Strain Diagrams.

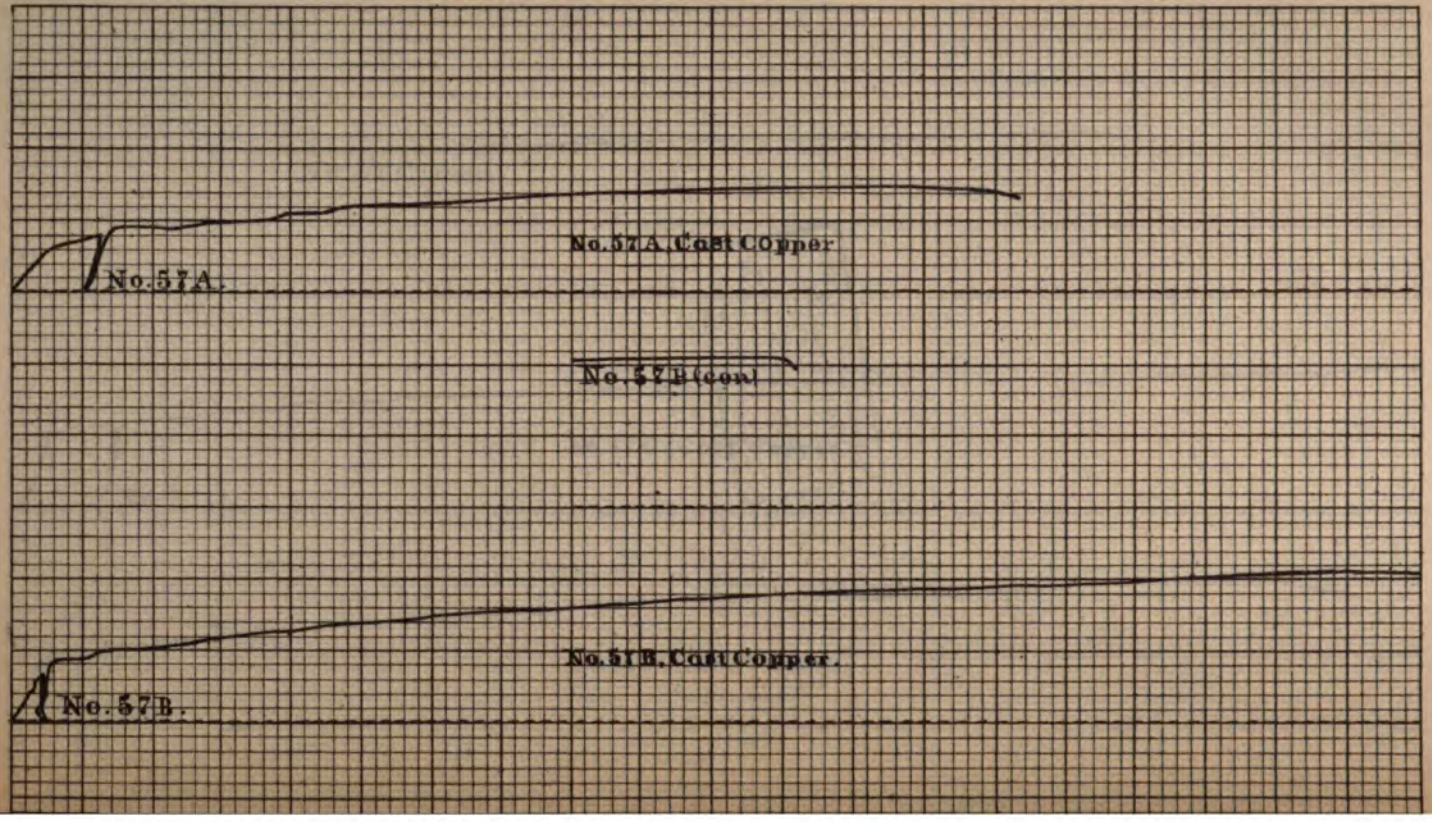


PLATE LXXIII.

Fac-Simile Autographic Strain Diagrams.

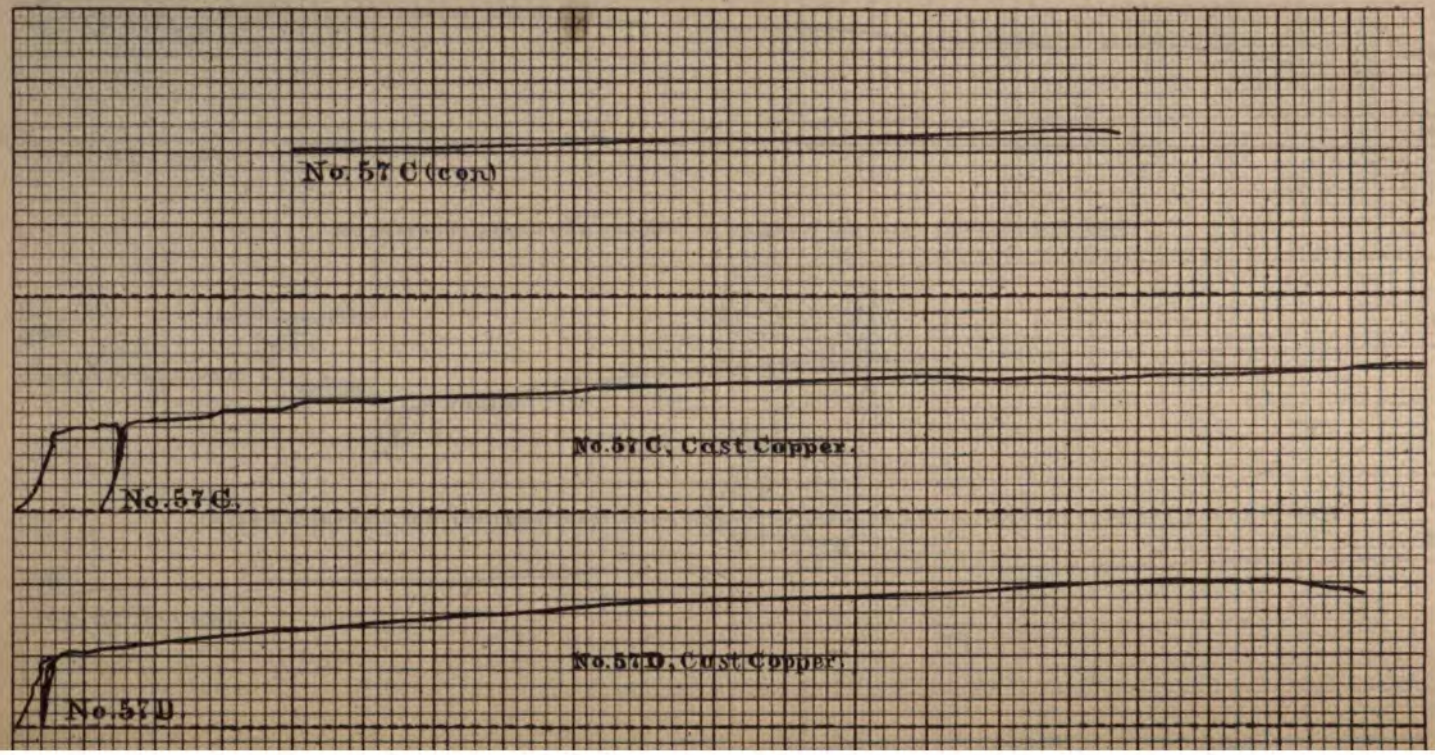


PLATE LXXIV.

Fac-Simile Autographic Strain Diagrams.

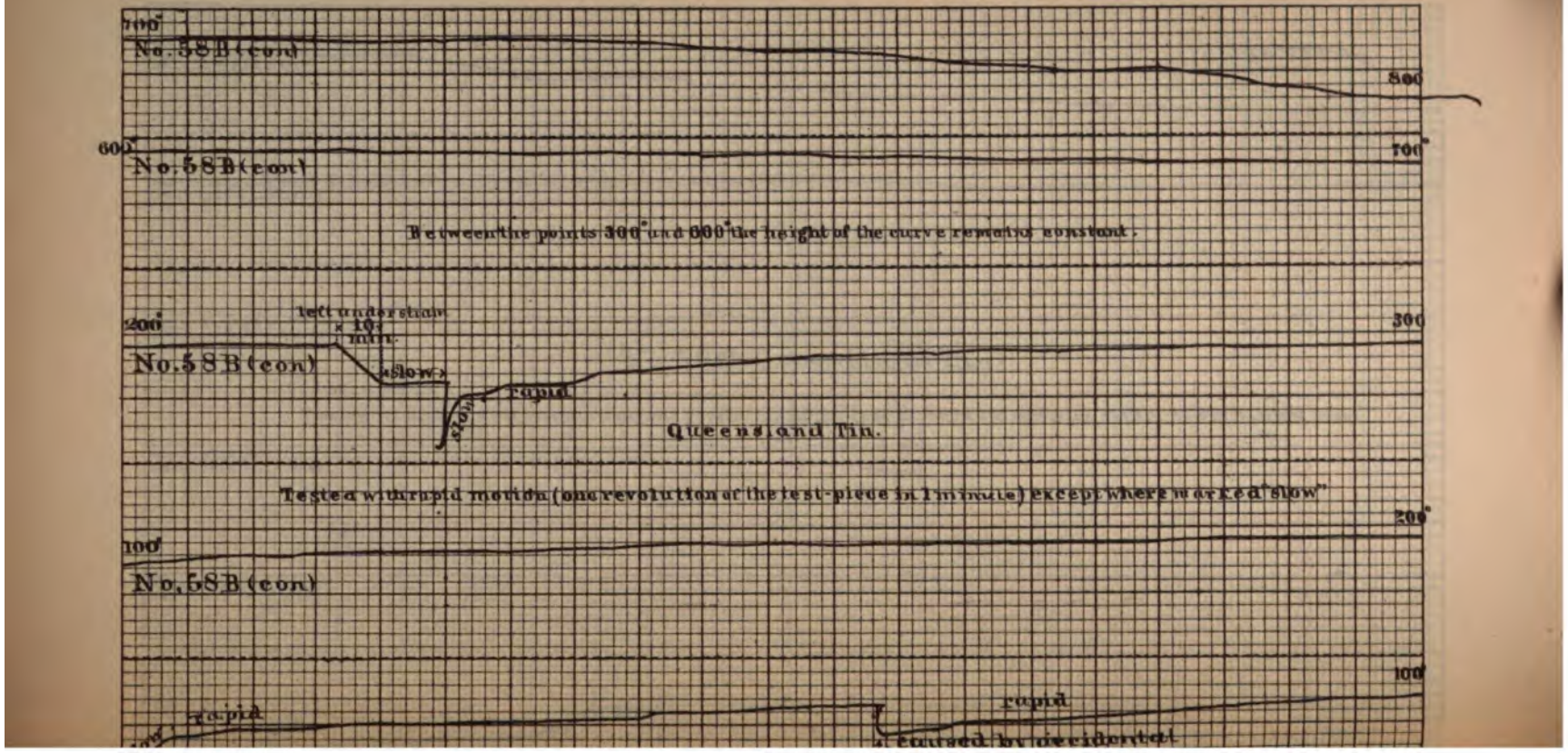


PLATE LXXV.

Fac-Simile Autographic Strain Diagrams.

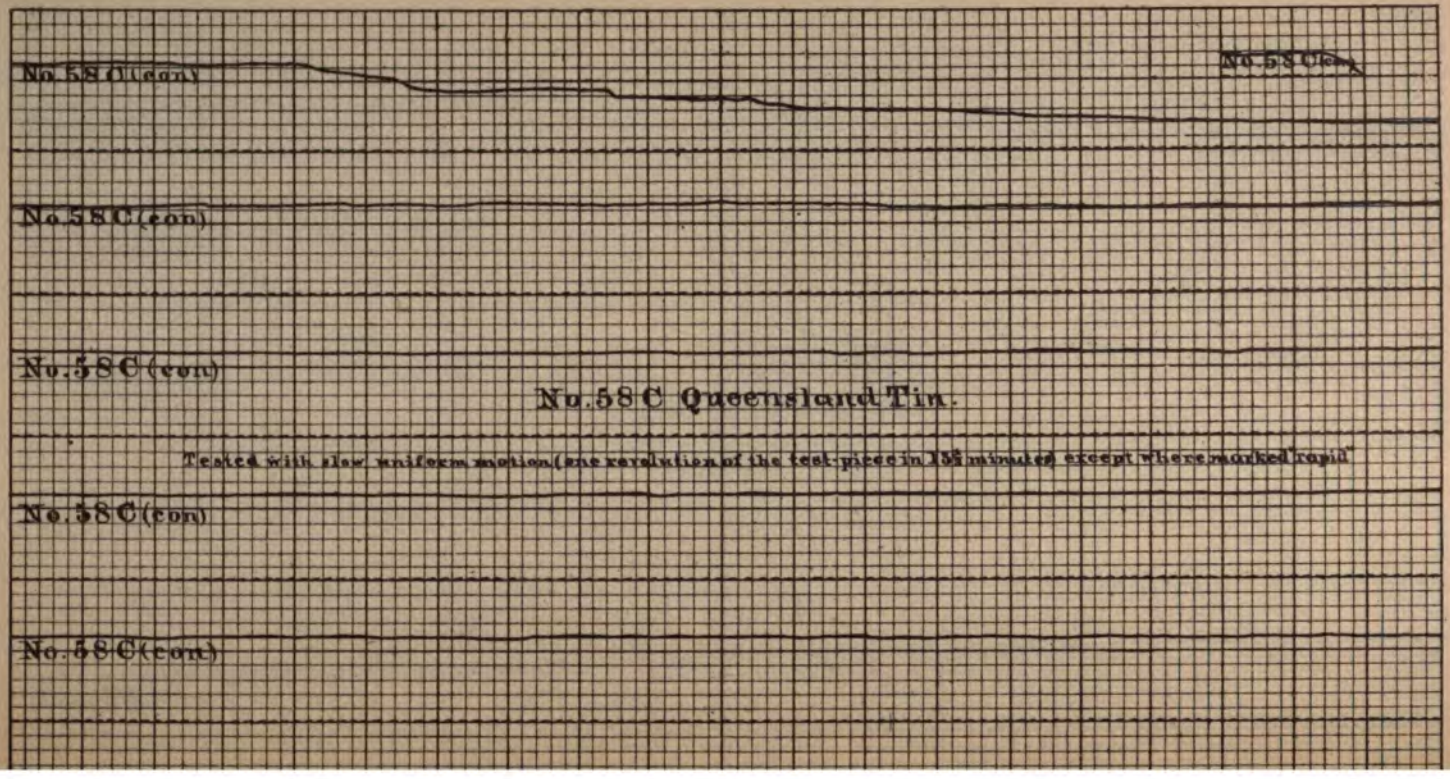
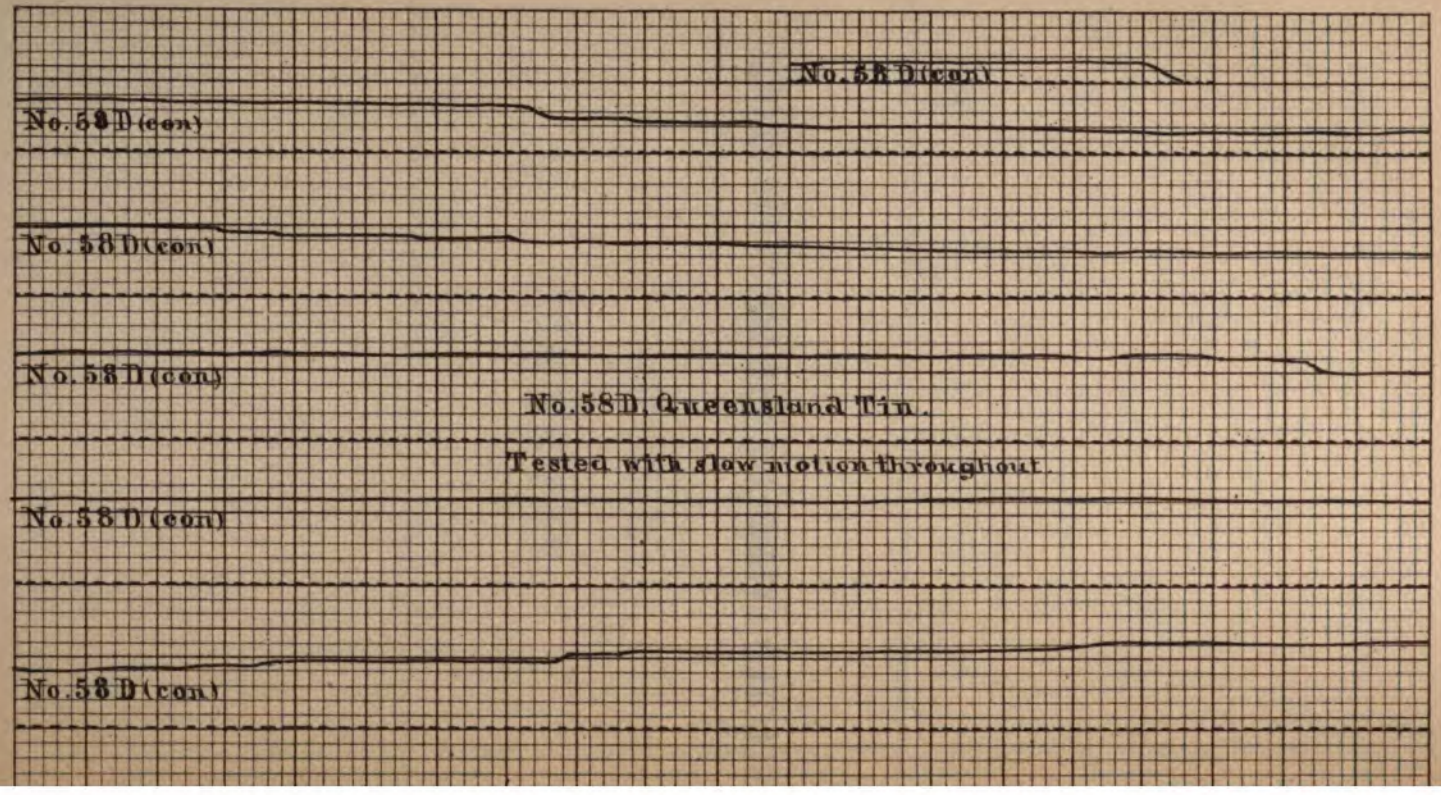

No.58C (con)
No.58C (con)
No.58C (con)
No.58C Queensland Tin.
Tested with slow uniform motion (one revolution of the test-piece in 15½ minutes) except where marked "rapid"
No.58C (con)
No.58C (con)

PLATE LXXVI.

Fac-Simile Autographic Strain Diagrams.



APPENDIX.

SELECTED PAPERS ON THE METALLIC ALLOYS.

LECTED PAPERS ON THE METALLIC ALLOYS.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

NOTE ON THE RESISTANCE OF MATERIALS.

Prof. Robert H. Thurston, Member of the Society. Read November 17, 1875.

ber 19, 1873, I had the pleasure of presenting to the society a
bsequently published in "Transactions"*) in which I made
ıe discovery of an increased power of resisting stress which was
l in iron and steel, by their subjection to a strain which pro-
stortion beyond the elastic limit and gave them a set. This
fully considered in a paper read April 4, 1874,† and the phe-
more thoroughly examined in its bearings upon the practical
the engineer, and the experimental researches by which its
ad been revealed were described. Subsequently Commander
ardslee, U. S. N., discovered the same principle independently
different method of experiment, and since the republication
facts in foreign periodicals, experimenters in Europe have an-
the observation of similar phenomena under identical or sim-
itions.

riter, since the announcement of this important peculiarity in
vior of metals, has made a very large number of experiments
ıs, steels, and on various alloys, as well as other simple metals,
ı many qualities of each. The Mechanical Laboratory of the
Institute of Technology has been called upon to test large num-
pecimens of commercial qualities of nearly every kind of metal
material of construction, and these often furnished opportuni-
ursue the investigation. The special work now in progress
e direction of the United States board recently appointed to
steel, and other metals, has been particularly useful in permit-
examination of the behavior of the copper-tin alloys.

sults of observation, so far as the experience of the writer has
nded, may be briefly summarized as follows:

ı, an elevation of the elastic limit very generally occurs under
a marked degree. It is very variable in maximum amount,
ıe time required to produce it. Some metals exhibit it to an al-
perceptible extent after long exposure to strain; other irons ex-
a great increase in their power of resistance to stress within
elastic limit, and its development may sometimes be the result
very brief period of exposure to the action of that molecular re-
ıent which seems to be the cause of this phenomenon. The
ı increase noted by the writer is about 30 per cent., and the time
for its development has sometimes not exceeded a half min-

ote on the Resistance of Materials; R. H. Thurston. Vol. II, page 239.
I. On the Mechanical Properties of Materials of Construction; R. H. Thurs-
III, page 1.

ute; in other cases, the elevation of the elastic limit has been scarcely perceptible after several days.

In steel, the same variation in the amount and in the time needed for its development has been noticed.

In the various other metals and in the alloys, this action has not been found to occur in any case where the material was inelastic; on the contrary, it has been found that inelastic metals—particularly tin and metallic alloys of similar mechanical properties—have, when exposed to constant stresses exceeding their so-called elastic limits, gradually and continuously yielded by a process of flow which, in some instances, was observed to proceed uninterruptedly for days together, and would apparently have continued until fracture ensued, could the experiment have been carried to that extent.

These experiments have led the writer to suppose, as intimated in the paper referred to, that the force of cohesion and that force which gives stability of form to solids and distinguishes them from liquids—a force called by Professor Henry "polarity"—are quite distinct modes of molecular action. Some materials, as the stronger of the ductile metals, exhibit great cohesion, and yet may flow under the action of a constant force, as in the cases last referred to above; while others—for example, over-hardened steel—may have great polarity, and consequently great stability of form, while exhibiting a relatively low power of cohesion.

It is in metals which belong to the latter class, rather than in those of the former character, that the elevation of the elastic limit by strain is observed. The explanation already proposed, that this apparent increase of resisting power is really a consequence of the relief of internal stresses due to methods of manufacture, or to circumstances which have, by external application of force, prevented such a molecular arrangement of particles as would naturally take place, still seems to the writer the most satisfactory explanation. The close relation of this action to that observed by Professor Johnson thirty years ago, and illustrated by the process termed by him "thermo-tension," has been pointed out on a former occasion.

During the two years which have elapsed since the first announcement of the phenomenon of the elevation of the elastic limit by strain, a large mass of valuable data has been accumulated, which may at some future time be collated. In no case, in the whole range of these researches, has any indication been observed of a reduction of resisting power during the distortion of metal between—on the one hand—the passing of the elastic limit, and—on the other hand—the point at which incipient rupture commences.

CONCLUSIONS.—The writer is therefore led to conclude that the simple extension or straining of any member of any metallic structure is not a cause of weakness, except where it produces an actual reduction of section resisting rupture, or where it brings the line of stress into a new direction, in which it acts either with a larger component of force in the former direction of stress, or, as in the case of a reflexure of the metal, it takes the material at disadvantage strategetically, after a new disposition of its particles has taken place.

The conclusion seems also proper, that the elevation of the elastic limit by strain can only occur in metals which are elastic, and are capable of being placed in a condition of reduced resisting power by internal stress by artificial or external force.

Finally, the conclusion has been arrived at, that structures are not weakened by stresses exceeding the elastic resisting power of their members, whatever the material of which they are composed; and even when

ade of metals having no elasticity and capable of yielding, like tin, by w, unless such strains as are produced are productive of actual molecu- r disruption.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

Incorporated 1852.]

TE ON THE RESISTANCE OF MATERIALS, AS AFFECTED BY FLOW AND BY RAPIDITY OF DISTORTION.

paper by Prof. Robert H. Thurston, Member of the Society. Presented March 1, 1876

The effect of the "flow of metals" and of the force of polarity described Professor Henry, in modifying their resistance to external stress and eir strain, was alluded to by the writer in preceding Transactions, as llows: *

The same molecular movement or flow which rearranges the internal force and ieves internal strain may be a phase of that viscosity which Vicat supposed might time permit rupture of metal subjected to stress nearly approaching its original imate resistance, the one action being a more immediate result than the other, and latter producing its effect, even when cohesive force may have been actually inten- ed.

It was noted, however, that in all cases in which wrought iron and el had been subjected to stress exceeding the elastic limit the metal d exhibited no tendency to flow, and that, in nearly every case ob- rved, an actual "elevation of the elastic limit by strain" had taken ace. No experiment had then been made by the writer in which the me sample had exhibited both the elevation of the elastic limit by rain and the phenomenon of flow.

Since that time, when experimenting upon copper, strain-diagrams oduced automatically have been observed to exhibit this double effect. ie elevation of the elastic limit has occurred in the earlier part of the st, and, at a later period, the strain-diagram exhibits flow, the metal elding under a gradually decreasing stress. The progressive distortion, hich had never been observed by the writer in iron or steel, has, since ie date of the paper, been frequently noted in other materials. For ample, the following are a few illustrations: †

TESTS BY TORSION.

	Material parts.		Time under stress.	Angle of torsion.	Fall of pencil.	Remarks.
	Tin.	Copper.		°		
1	.....	.....	40 hours ..	65	0.06 inches..	Recovered after further distortion of 1°.
2	100	.....	1 hour ...	180	0.1 inch....	Recovered in 8°.
3	.....	.....	2 hours ..	280	0.1 inch....	Recovered in 80°.
4	99.44	0.56	12 minutes	†380	50 per cent..	Did not recover.
5	98.89	1.11	.....	.....	.....	Behaved like No. 4.
6	Alloy.		.....	58	0.2 inches..	Did not recover.

* Same piece. † Taking elasticity line.

* LXXXII. On the Mechanical Properties of Materials of Construction. Vol. III ge 13.

† Selected from the record books of the Mechanical Laboratory of the Stevens Insti- te of Technology.

TESTS BY TRANSVERSE STRESS—WITH DEAD LOADS.

Samples 1 × 1 × 22 inches.

No. of test.	Material parts.		Load.	Deflection.	Time.	Increased deflection.	Brea wei
	Tin.	Copper.	*Pounds.*	*Inches.*		*Inches.*	Pou
7	.....	100	600	0.534	5 minutes	0.009	
8	1.9	98.1	475	1.762	3 minutes	0.291	.....
			500	2.108	3 minutes	0.488	
9	7.2	92.8	950	0.348	5 minutes	0.081	1
10	10.	90.	950	0.395	5 minutes	0.021	.....
			1,485	3.447	13 minutes	4.087	1
11	90.3	9.7	100	0.085	10 minutes	0.021	.....
			120	0.140	10 minutes	0.055	.....
			140	0.221	10 minutes	0.098	.....
			140	0.319	10 minutes	0.038	.....
			140	0.357	40 hours.....	0.920	.....
			160	1.294	10 minutes	0.025	.....
			160	1.320	1 day.....	1.000	.....
			160	2.320	1 day.....	1.001	.....
			160	3.320	1 day.....	1.000	
12	98.89	1.11	90	0.243	5 minutes	0.063	.....
			120	0.736	15 minutes	1.055	.....
			120	1.791	30 minutes	0.748	.....
			120	2.539	45 minutes	0.595	.....
			120	3.134	12 hours.....	8.000	
13	100	.....	80	0.218	5 minutes	0.064	

Metals having a composition intermediate between these extre have not been observed to exhibit flow or to increase deflection und constant load.

Tests by tension with similar materials exhibit similar results, these observations and experiments thus seem to confirm the remark the writer as above quoted, and to indicate that, under some conditi the phenomena of flow and of elevation of the elastic limit by strain be coexistent, and that progressive distortion may occur with "visc metals.

The paper referred to enunciated a principle which had been dedu from experiments on wrought iron, which is, if possible, of more vital portance to the engineer than the facts just given, viz: "That the during which applied stress acts is an important element in determi its effects, not only as an element which modifies the effect of the *vis* of the attacking mass and the action of the inertia of the piece attac but also as modifying seriously the conditions of production and r of internal strain by even simple stresses."*

It was then shown, by autographic strain-diagrams, that some m rials yield the more readily the more rapidly the distortion and rup are produced, their resistance varying in some inverse ratio with rapidity of change of form. It was further suggested that this ac might be closely related to the opposite phenomenon of the elevatio the elastic limit by strain. An explanation was offered in the theory t with rapid distortion, insufficient time is allowed for the relief of inte strain in materials capable of exhibiting that condition. It was fu remarked that "the most ductile substances may exhibit similar beha when fractured by shock or by any suddenly-applied force, to substa which are comparatively brittle," and illustrations were given of behavior, and the precautions to be taken by the engineer, in view o important modification of the resistance of materials by velocity of ture, were stated.

The writer has continued his experimental researches, with occas

*Vol. III, page 30.

rruption, since that time, and has found the above-given statements firmed, and that relations exist between these phenomena of strain the time under stress, which may properly be stated here as comple- ıtary of the principles already published in the two preceding notes ch have appeared in Transactions.*

hould it be true, as suggested by the writer, that the cause of the reased resistance, sometimes observed with increased velocity of dis- ion, is closely related to the cause of the elevation of the elastic limit strain,† it would seem a simple corollary that *materials so inelastic so viscous as to be incapable of becoming internally strained during dis- ion, should offer greater resistance to rapid than to slowly-produced dis- ion*, in consequence of their inability to "flow" so rapidly as to reduce stance by such fluxion at the higher speed, or by correspondingly acing the fractured section. This principle has been shown, by a e number of experiments, to be frequently, if not invariably, the fact. per, tin, and other inelastic and ductile metals and alloys are found xhibit this behavior, and are therefore quite opposite in this respect rdinary wrought iron and worked steel.

he writer has noted the fact that very soft wrought iron does not ays exhibit an observable elevation of the elastic limit by strain, and mander L. A. Beardslee, U. S. N.,‡ has recently observed that the soft- and most ductile specimen of iron yet tested by him at the Washington y Yard exhibited a perceptible increase of resistance with a consid- le increase of rapidity of extension. This metal was peculiar in its ness and extreme extensibility. All the irons of commerce appear elong to the other class.

he records of the Mechanical Laboratory of the Stevens Institute of nology frequently illustrate the proposition that metals which gradu- yield under a constant load offer increased resistance with increased city of rupture.

he curves of deflections of a considerable number of ductile metals alloys are very smooth when the time during which each load has n left upon them is the same; but whenever that time has been vari- the curve has been irregular. Bars of such metals broken by trans- e stress give a greater resistance to rapidly-increasing stress than to ss slowly intensified. Two pieces of tin from the same bar were en by tension, the one rapidly and the other slowly. The first broke er a load of 2,100 and the latter of 1,400 pounds. The example illus- es well the very great difference which is possible in such cases, and s to the writer to indicate the possibility in extreme cases of obtain- results which may be fatally deceptive when the time of rupture is noted.

he depression of the elastic limit has been observed previously in erials, but less attention has been paid to it than the importance of phenomenon would seem to demand. The accompanying plate ex- ts the strain-diagrams produced by plotting the results of experi- ts.§ They are selected as typical examples, and as representing the classes of materials described.

n making the experiments the bar was mounted on cylindrical steel rings, which were themselves supported on accurately planed level faces, and the deflection was produced by means of a powerful screw a large hand-wheel. The weight was measured by a Fairbanks scale

XLI. Vol. II, page 239. CXV. Vol. IV, page 334.
Transactions, Vol. III, page 363.
Whose work has been referred to in earlier papers.
Made and recorded in the Mechanical Laboratory of the Stevens Institute of Tech- gy.

combination, and the deflections and sets by a special measuring apparatus* which reads to 0.0001 inch, with an error of 0.000741. Touch is indicated by a delicate Stackpole level. The measuring instrument was unaffected by the forces tending to distort the straining apparatus. The deflecting force was adjusted by the scale-beam. The bar being in place, the weight to be put on it was set off on the scale-beam, and the screw was carefully turned until, by its pressure on the middle of the bar, the scale-beam slowly rose and vibrated about the middle of its range, which point was indicated by a pointer at the end of the beam, traversing a fine-lined scale on the frame. When the adjustment had become satisfactory the deflection was read off and the beam usually released, in order that the set might be observed. It was then again deflected by a heavier weight. Occasionally the bar was left thus strained, and with a constant deflection, for a considerable period of time, and the change of effort exerted by it noted at frequent intervals. In all such cases the scale-beam gradually drooped, and a decreased effort to effect restoration of form was indicated. When the beam had fallen, the weight was pushed back until the beam arose and vibrated about the center line again, and the weight and time were recorded. This was repeated as the beam exhibited less and less loss of power of restoration, and when this decrease of effort no longer exhibited itself a new series of deflections was produced.

The bar No. 599, which was quite ductile, exhibited an unchanged law of relation of amount of deflection to intensity of deflecting force, and, as shown by the diagram, the curve representing its test pursued the same general direction after one of these "time-tests" as before.

The loss of effort at 163 pounds is seen to have been about 20 pounds, the deflection amounting to 0.0347 inch, and the effort falling from 163 to 143 pounds. At 403 pounds the loss of restorative force is about the same; the figures fall from 403 to 333 pounds, the deflection being held constant at 0.0886 inch, again from 333 to 302 pounds at a deflection of 0.0896, and still again from 1,233 to 1,137 pounds at a deflection of 0.5208 inch.

Before the bar, under further deflection, had quite regained its original resisting power, the "time-test" was repeated, the deflection amounting to 0.5456 inch, and the weight applied being 1,233 pounds. The result noted was quite unanticipated. The effort steadily decreased at a varying rate, which is indicated by the diagram of time and loads, and the bar finally snapped sharply, and the two halves fell upon the floor. The effort had decreased to 911 pounds. The deflection was precisely what it had been under the load of 1,233 pounds. The beam had balanced at 911 pounds for about three minutes when the fracture took place. An assistant was sitting fifteen or twenty feet from the machine at the instant, but no one had approached the machine after the last adjustment of the weight.

This is a case without parallel in the experience of the writer, and its conclusion indicates a possibility of depreciation in resisting power of the class of metals of which tin has been taken as the type, which depreciation, in the present state of our knowledge of the properties of such metals in this regard, it may be safest to assume to be a source of danger in some cases in which the load approaches the maximum resisting power of the piece. This illustrates the case of progression of flow until the section most strained has been weakened to the point of actual molecular disruption, which disruption would seem to have been here produced the effort of other and less injured portions to resume their orig

* Made to the order of the writer, by Messrs. Brown & Sharpe.

s, and to straighten the two halves of the bar. It would seem h action should be determined by flow occurring in a somewhat ut still somewhat elastic metal.

train diagram of this bar is seen to be nearly hyperbolic; but of Hooke, *ut tensio sic vis*, holds good, as usual, up to a point at ne load is about one-half the maximum. The curve of times and xhibits the rate of loss of effort while the bar was finally held lection of 0.5456 inch, the load being carefully and regularly re- as the effort diminished, from 1,233 to 911 pounds, at which gure the bar broke. The curve is a very smooth one. The fol- s the record of the test:

BAR No. 599.

90 parts zinc, 10 parts copper: 1 × 0.992 × 22 inches.

Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
Inches.	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
0.0033	.....	363	0.0781	.....	3	.....	0.0336
0.0078	.....	403	0.0881	.....	643	0.1641	.....
0.0127	.....	3	.....	0.0079	803	0.2149	.....
0.0225	.....	403	0.0886	.....	1,003	0.3178	.....
0.031	.....	Resistance fell in 8 h. 30 m.			1,103	0.3921	.....
0.0347	.....	to 333	0.0886	.....	1,203	0.481	.....
nce fell in 15 h. 25 m.		3	.....	0.0246	1,233	0.5209	.....
0.0347	.....	333	0.0896	.....	Resistance fell in 15 m.		
.....	0.0039	Resistance fell in 15 h.			to 1,137	0.5209	.....
0.0391	.....	to 302	0.0896	.....	3	.....	0.2736
0.0471	.....	303	0.0876	.....	1,137	0.5131	.....
0.0544	.....	403	0.1072	.....	1,233	0.5456	.....
0.0611	.....	503	0.1282	.....			
0.0692	.....	603	0.1521	.....			

ar was left under strain $11^h\ 22^m$ a. m., and the effort to restore easured at intervals, as follows:

R.—$11^h\ 37^m$; $11^h\ 50^m$, a. m.; $12^h\ 2^m$; $12^h\ 8^m$; $12^h\ 25^m$; $12^h\ 39\frac{1}{2}^m$; ^{m}; $12^h\ 58\frac{1}{2}^m$; $1^h\ 20^m$, p. m.

RT.—1,133; 1,093; 1,070; 1,063; 1,043; 1,023; 1,003; 993; 911

$^h\ 23^m$ p. m. the bar broke.

xample of somewhat similar behavior, but exhibited by a metal different quality, is shown on the next page.

bar was hard, brittle, and elastic, but must apparently be classed n in its behavior under either continued or intermitted stress.

e seems to the writer to exist a distinction, illustrated in these etween that "flow" which is seen in these metals, and that to as been attributed the relief of internal stress and the elevation elastic limit by strain and with time.

last phenomenon—the exaltation of the elastic limit by strain— en observed very strikingly by the writer in the deflection of rs by transverse stress. The plate exhibits the strain-diagrams d by transverse deflection of 4 bars of ordinary merchant wrought hich were all cut from the same rod. Of these, two were tested machine above described, in which the deflection remains con- hen the machine is untouched while the load gradually decreased, e properly, while the effort of the bar to regain its original form ses. The other two were tested by dead loads, the load remain- stant while the deflection may vary when the apparatus is left f. (The record is given on pages 11–14.)*

*Pages 478–480 of this report.

BAR No. 596.

75 parts zinc, 25 parts copper; second casting; 0.985 × 0.985 × 22 inches.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	S
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*In*
23	0.0057	.....	423	0.073	.....	to 473	0.0866	.....
63	0.0142	.....	463	0.0799	.....	3	.....	.....
103	0.0207	.....	503	0.0866	.....	503	0.0894	.....
143	0.0275	.....	3	.....	0.0014	543	0.0932	.....
183	0.0346	.....	503	0.0866	.....	583	0.1012	.....
223	0.0414	.....	Resistance fell in 5 h.			603	0.1042	.....
263	0.0485	.....	to 429	0.0866	.....	623	0.1075	.....
303	0.0549	.....	3	.....	0.0074	643	0.1102	.....
343	0.0610	.....	429	0.0866	.....	663	0.1136	.....
383	0.0669	.....	Resistance fell in 13 h. 30 m.			Broke 5 seconds after wi ing sound.		

These two pairs of specimens were broken; one in each set by ing weight steadily until the end of the test, so as to give as little for elevation of elastic limits as was possible; and one in each se intermittent stress, observing sets, and the elevation of the el limit.

If the long-known effects of cold-hammering, cold-rolling, and drawing in stiffening, strengthening, and hardening some metals be, as the writer is inclined to believe, attributed in part to this mo lar change, as well as to simple condensation and closing up of ties and pores, this exaltation of the elastic limit by distortion u externally applied force has now been shown to occur in iron an metals of that class in tension, torsion, compression, and under t verse strain.

Referring to the plate, it will be seen that there is exhibited the a in the latter case even more fully and strikingly than in the re above given, and a study of these typical examples cannot fail to p both interesting and instructive.

TESTS OF WROUGHT-IRON BARS BY TRANSVERSE STRAIN.

Samples 1 inch square, 28 inches long; 22 inches between supports.

No. 648.– TESTED IN FAIRBANKS' MACHINE.

Load.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	
Pounds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	
103	0.0132	.....	Resistance fell in 2 h.			1,831	0.8471	.....
203	0.0244	.....	to 1,187	0.121	.....	2,003	0.8641	.....
Resistance fell in 13 h. 35 m.			3	.....	0.0096	2,071	0.8819	.....
to 199	0.0244	.....	1,203	0.1226	.....	2,081	0.9396	.....
303	0.0342	.....	1,243	0.1266	.....	3	.....	.....
403	0.0428	.....	1,283	0.1301	.....	2,081	0.9886	.....
Resistance fell in 1 h. 30 m.			1,323	0.1354	.....	Resistance fell in 21 h		
to 399	0.0428	.....	1,741	0.7031	.....	to 1,871	0.9886	.....
3	.....	0.0042	1,911	0.7246	.....	3	.....	.....
503	0.0528	.....	1,921	0.7566	.....	1,911	0.9904	.....
603	0.0619	.....	3	.....	0.5746	2,083	1.0106	.....
Resistance fell in 4 h.			1,921	0.7746	.....	2,121	1.0496	.....
to 598	0.0619	.....	Resistance fell in 21 h. 48 m.			2,131	1.0911	.....
803	0.0806	.....	to 1,767	0.7746	.....	3	.....	.....
Resistance fell in 15 h. 15 m.			3	.....	0.6028	2,131	1.1316	.....
to 789	0.0806	.....	1,767	0.7726	.....	1,363	0.1421	.....
903	0.0907	.....	1,931	0.7876	.....	1,403	0.1504	.....
1,003	0.0995	.....	1,995	0.8036	.....	3	.....	.....
Resistance fell in 5 h. 20 m.			2,001	0.8266	.....	1,403	0.1522	.....
to 987	0.0995	.....	3	.....	0.6451	Resistance fell in		
3	.....	0.0049	2,001	0.8498	.....	to 1,387	0.1522	.....
1,203	0.1197	.....	Resistance fell in 21 h. 30 m.			Resistance fell in 2 h		
3	.....	0.0071	to 1,831	0.8498	.....	to 1,361	0.1522	.....
1,203	0.121	.....	3	.....	0.6780			

ESTS OF WROUGHT-IRON BARS BY TRANSVERSE STRAIN—Continued.

ad.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
nds	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
sistance fell in 39 h. 5 m.			2,091	1.6166	.....	2,501	2.2121	.....
329	0.1522	.....	1,603	0.4346	.....	3	.....	1.9886
3	.....	0.0246	1,711	0.4456	.....	2,501	2.2471	.....
329	0.1451	.....	1,753	0.4513	.....	Resistance fell in 14 h. 10 m.		
403	0.1522	.....	1,781	0.4651	.....	to 2,295	2.2471	.....
483	0.16	.....	Resistance fell in 6 h. 3 m.			3	.....	2.0331
523	0.1647	.....	to 1,661	0.4651	.....	2,295	2.2456	.....
563	0.1761	.....	3	.....	0.3106	2,541	2.2762	.....
603	0.2548	.....	1,675	0.4676	.....	2,561	2.3102	.....
3	.....	0.1091	1,787	0.4808	.....	3	.....	2.0763
603	0.287	.....	1,811	0.5446	.....	2,561	2.35	.....
sistance fell in 6 h. 3 m.			3	.....	0.3771	Resistance fell in 6 h. 18 m.		
457	0.287	.....	1,811	0.5661	.....	to 2,369	2.35	.....
3	.....	0.1451	Resistance fell in 46 m.			3	.....	2.1402
457	0.2863	.....	to 1,675	0.5661	.....	2,369	2.3587	.....
503	0.3016	.....	Resistance fell in 17 h.			2,551	2.3782	.....
03	0.3921	.....	to 1,661	0.5661	.....	2,571	2.3854	.....
3	.....	0.2431	3	.....	0.4081	2,591	2.4287	.....
03	0.4301	.....	1,661	0.5645	.....	3	.....	2.1952
istance fell in 20 h. 50 m.			1,801	0.578	.....	2,591	2.5044	.....
41	0.4301	.....	1,861	0.5886	.....	Resistance fell in 15 h. 4 m.		
3	.....	0.2846	1,877	0.6034	.....	to 2,371	2.5044	.....
41	0.4296	.....	1,891	0.6626	.....	3	.....	2.2842
istance fell in 47 h. 37 m.			3	.....	0.4938	2,371	2.5022	.....
39	1.1316	.....	1,891	0.7001	.....	2,591	2.5247	.....
3	.....	0.958	Resistance fell in 10 s.			2,611	2.5334	.....
41	1.1358	.....	to 1,801	0.7001	.....	2,631	2.5927	.....
81	1.1551	.....	Resistance fell in 6 m.			3	.....	2.3577
21	1.1686	.....	to 1,737	0.7001	.....	2,631	2.653	.....
01	1.1981	.....	Resistance fell in 5 h. 23 m.			Resistance fell in 8 h. 2 m.		
11	1.2356	.....	to 1,721	0.7001	.....	to 2,371	2.653	.....
3	.....	1.0361	3	.....	0.5406	3	.....	2.4227
istance fell in 9 h.			2,311	1.6466	.....	2,371	2.6532	.....
97	1.2356	.....	2,341	1.6996	.....	2,631	2.6833	.....
3	.....	1.1158	2,351	1.7321	.....	2,651	2.6992	.....
01	1.3016	.....	3	.....	1.5196	2,661	2.7307	.....
11	1.3326	.....	2,351	2.0446	.....	3	.....	2.4987
31	1.3656	.....	Resistance fell in 16 h.			2,661	2.8324	.....
37	1.3936	.....	to 2,135	2.0446	.....	Resistance fell in 61 h. 32 m.		
3	.....	1.1946	3	.....	1.8441	to 2,363	2.8324	.....
41	1.4441	.....	2,135	2.0431	.....	3	.....	2.5924
istance fell in 13 h. 50 m.			2,355	2.0646	.....	2,363	2.8286	.....
41	1.4441	.....	2,391	2.0736	.....	2,685	2.8627	.....
3	.....	1.2538	2,411	2.1136	.....	2,701	2.871	.....
41	1.4421	.....	3	.....	1.8964	2,710	2.8917	.....
241	1.4631	.....	2,411	2.1451	.....	2,720	2.9297	.....
281	1.4821	.....	Resistance fell in 8 h. 35 m.			3	.....	2.647
301	1.5216	.....	to 2,238	2.1451	.....	2,720	2.9692	.....
311	1.5531	.....	Gradually reduced strain			Resistance fell in 5 h. 48 m.		
3	.....	1.3436	to 3*	.....	1.9266	to 2,483	2.9692	.....
311	1.6166	.....	Gradually increased strain			3	.....	2.7357
sistance fell in 8 h. 8 m.			to 2,238*	2.1336	.....			
091	1.6166	.....	2,411	2.1516	.....	Bar removed: test ended.		
3	.....	1.4181	2,491	2.1811	.....			

radually reduced strain to 3 pounds, taking a number of readings; then gradually increased it to pounds, taking readings corresponding to former ones; found that increase of deflection was pro- onal to increase of load.

No. 649.—TESTED IN FAIRBANKS' MACHINE.

ad.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
nds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
103	0.0139	900	0.0889	1,462	0.1505	In 2¼ m. was	0.3629
200	0.0238	1,000	0.0982	1,480	0.1569	1,620	0.3704
300	0.0328	1,100	0.1081	1,500	0.1619	1,640	0.3831
405	0.0425	1,200	0.1171	1,520	0.1709	In 6 m. was	0.4404
500	0.0519	1,300	0.1279	1,540	0.1804	1,660	0.4479
600	0.0602	1,400	0.1398	1,560	0.2078	*b*1,680	0.4599
700	0.0689	1,420	0.1435	1,580	0.2429	.....	.....
800	0.0787	1,442	0.1472	*a*1,600	0.2854	2,350	5.577

t 1,600 pounds the beam sank instantly; ran the pressure-screw down so as to keep the beam bal- l for 2¾ m., with increase of deflection as noted.
t 1,680, ran pressure-screw rapidly but steadly down, moving the poise along the beam to keep it ced. The beam vibrated up and down, falling or rising instantly as the wheel was turned slower ter. The resistance reached a maximum of 2,350 pounds, when the deflection was 5.577 inches.

No. 650.—TESTED BY DEAD LOADS.

Load.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds*	*Inches.*	*Pounds.*	*Inches.*
100	0.015	400	0.0425	800	0.0858	1,400	0.170
200	0.0229	600	0.0638	1,200	0.1456	c1,500	0.210

c At 1,626, the reading was not taken. Weights as follows were rapidly added, 4 or 5 pieces each minute, as follows: 82, 25, 42, 15, 16, 10, 15.5, 16, 25, 25, 25, 13, 11.5, 16.27, 62, 40.5, 61, 45, 62 = 2,260.5 pounds. The bar sank rapidly, its side pressure splitting the wood which confined the mandrels. The set measured after the bar was removed, 2.5 inches. The total deflection is calculated as follows: the elasticity of the bar remaining the same, the increase of deflection over set is directly proportional to the load. (This is shown by the parallelism of the elasticity lines with the original line within the elastic limit). Thus at 800 pounds, the set was inappreciable, deflection 0.0858; whence 800 : 0.0858 :: 2,260 : 0.242 difference of deflection and set; set was 2.5, hence calculated deflection 2.742 inches.

No. 651.—TESTED BY DEAD LOADS.

Load.	Deflection.	Load.	Deflection.	Load.	Deflection.	Load.	Deflection.
Pounds.	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*
100	0.0158	In 5 h. 46 m. was	0.6598	In 48 h. 30 m. was	1.9245	2,452	3.072
200	0.0275	1,700	0.67	2,222	1.9379	2,484	3.097
400	0.0489	In 3 m. was	0.6716	2,288	2.13-6	In 39 h. 40 m.	4.238
600	0.0709	In 16 h. was	0.7615	In 12 m. was	2.9535	In 43 h. 20 m.	4.251
803	0.0913	1,800	0.771	2,266	2.9928	2,513	4.263
1,000	0.1141	1,900	1.0904	In 17 m. was	3.0157	2,556	4.307
1,200	0.1394	In 3 h. 15 m. was	1.8567	In 3 h. 37 m. was	3.0236	In 4 h. 20 m.	4.250
1,400	0.1701	In 45 h. 45 m. was	1.8709	2,288	3.029	2,589	4.276
1,500	0.2465	2,005	1.8787	2,350	3.0426	In 48 h. was	4.320
In 8 m. was	0.4307	In 3 h. was	1.8819	2,370	3.0434	In 61 h. 30 m. was	4.320
1,600	0.489	2,052	1.8886	In 25 h. 15 m. was	3.0677	Weights reached support. Test was ended.	
In 6 m. was	0.6504	2,115	1.8921	2,422	3.0701		

The strain-diagrams exhibited in the plate do not present to the eye one of the most important distinctions between the two classes of metals. As seen by study of these diagrams, both classes, when strained by flexure, gradually exhibit less and less effort to restore themselves to their original form.

In the case of the tin-class, this loss of straightening power seems often to continue indefinitely, and, as in one example here illustrated, even until fracture occurs.

With iron and the class of which that metal is typical, this reduction of effort becomes gradually less and less rapid, and finally reaches a limit after attaining which, the bar is found to have become strengthened, and the elastic limit to have become elevated. In this respect, the two classes are affected by time of strain, in precisely opposite ways.

The plate exhibits, even better than the record, the superior ultimate resistance of the bars which have been intermittently strained, as well as the elevation of the elastic limit. This parallelism of the "elasticity lines" obtained in taking sets, shows that the modulus of elasticity is unaffected by the causes of elevation of the elastic limit.

Evidence appealing directly to the senses has been presented in the course of experiment on the second class of metals, of the intra-molecular flow. When a bar of tin is bent, it emits while bending the peculiar crackling sound, familiarly known as the "cry of tin." This sound has not been observed hitherto, so far as the writer is aware, when a bar has been held flexed and perfectly still. In several cases recently, in experiments on flexure* of metals of the second class, bars held at a constant deflection have emitted such sounds hour after hour, while taking set and losing their power of restoration of shape.

* Made in the Mechanical Laboratory of the Stevens Institute of Technology.

During some of the experiments made, a very marked illustration of e decrease of set with time, which has been observed and described by of. W. A. Norton, has been noted, and the recovery of straightening wer in the deflected bar has sometimes been strikingly large, amount- to nearly 30 pounds in 15 minutes. A record of one of these bars is—

BAR No. 563.

17.5 parts copper, 82.5 parts tin; 0.986 × 0.993 × 22 inches.

oad.	Deflection.	Set.	Load.	Deflection.	Set.	Load.	Deflection.	Set.
unds.	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Inches.*
10	0.0027	.....	140	0.0804	.....	300	0.4597	.....
20	0.007	.....	180	0.1343	.....	5	.....	0.3084
40	0.0153	.....	200	0.1666	.....	Set decreased in 2 h. 20 m.		0.2845
60	0.0256	.....	5	.....	0.0821			
80	0.0365	.....	200	0.1798	.....	to 300	0.5332	.....
100	0.0499	.....	240	0.2503	.....	310	Bar broke in putting on strain.	
5	.....	0.0092	280	0.3762	.....	.....		

After 300 pounds had been placed on the bar, and the reading taken, e screw was run back till the beam just balanced at 5 pounds, the essure-block attached to the screw barely touching the bar. The was then read, as above, 0.3084 inch, the beam slowly rising. The essure-screw was then run back till beam again balanced at 5 pounds, d the set measured 0.3022 inch; the time was 2 minutes. The am again rose, poise on beam was pushed forward and balanced at pounds; the time was 2 minutes. In two minutes more beam balanced 14 pounds. The pressure-screw was again run back till beam balanced 5 pounds, and the set measured 0.2998 inch. The beam rose again 11 hours 37 minutes, a. m. In 2 minutes it balanced at 10 pounds, in minutes at 16 pounds, and in 29 minutes at 23 pounds. The beam s again balanced at 5 pounds, set measured 0.2902 inch. The beam e in 4 minutes. In 29 minutes the beam balanced at 14 pounds, and 65 minutes more it balanced at 20 pounds. The beam was again bal- ced at 5 pounds, and the set measured 0.2845 inch. The total decrease set in 2 hours 20 minutes was 0.3084—0.2845=0.0239 inch. Then re- ced 300 pounds, and read deflection 0.5332 inch; increased the press- , but the bar broke before 310 pounds was reached.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

E RATE OF SET OF METALS SUBJECTED TO STRAIN FOR CONSIDERABLE PERIODS OF TIME.

aper by Prof. Robert H. Thurston, Member of the Society. Read December 6, 1876.

ECTION I.*—*On the observed decrease of resistance at a fixed distor- n.*—The writer has, in a preceding paper,† shown by reference to ex- imental researches in which he had then engaged, that some classes metals, as ordinary iron and steel, when subjected to strain and distor-

Prepared July, 1876.

CXXIII. Note on the resistance of materials as affected by flow, and by rapidity of tortion, vol. v, page 199; also "Van Nostrand's Engineering Magazine," September, 6, and "Engineering" (London), December 29, 1876.

tion by a force exceeding the resistance of the material within the elastic limit, take a set and are stiffened by that act, and exhibit an exaltation of the elastic limit. It was also shown that other classes, like tin and similarly viscous and ductile materials, exhibit flow and a depression of their limits of elasticity when similarly treated.* It was further shown that the former class, when subjected to loads even approaching their ultimate strength, took a certain set and remained apparently indefinitely without further distortion; while the second class, under very moderate loads, frequently exhibited a gradual yielding, a progressive distortion, until fracture took place, sometimes under stresses which were but a fraction of those which were found required to break such metals quickly, and when time was not allowed for flow to occur. It was noted that increase of rapidity of distortion and fracture produced increase of resistance in the latter, or "tin class," and decrease of resisting power in the first, or "iron class," and *vice versa*.

The writer has since instituted experiments upon metals of both classes to determine how rapidly set, in each class, took place; the earlier experiment just referred to having confirmed a suspicion long existing among engineers and experimentalists that the phenomenon was a molecular change as well as of the mass, and that time was required for its complete development. Professor Norton has also shown by experiment that this set is partially temporary, the bar relieving itself of distortion in some degree on removal of the load. Both that experimenter and the writer had detected some peculiar variations of form during this recovery, and the experiments of the latter, as detailed in the preceding paper, exhibited at times a gradual recovery of straightening power in a confined and flexed bar. The following will be found interesting, and perhaps important, as showing how these molecular changes progress:

Bars were prepared of square section, 1 inch in breadth and depth, and 22 inches in length between bearings. They were flexed in a machine† for testing the resistance of materials to transverse stress, as described in the preceding paper, and the load and deflection carefully measured. As the bars were retained at a constant deflection, their effort to resume their original form gradually decreased, and the amount of this effort was from time to time noted. When this effort or resistance had become considerably decreased, the bar was released and the set measured. This operation was repeated with each, until the law of decrease of elastic resistance was detected. Curves were constructed, illustrating graphically this law, and exhibiting it more satisfactorily and more plainly than the tabular record.

The following is the record for the bars of iron, of tin, and of two alloys: The iron bar No. 648 was subjected to a load of 1,003 pounds, somewhat less than one-half its maximum, and its deflection was found to be 0.0995 inch. Removing the load, the set was 0.0049 inch. Restoring the load (1,000 pounds, + 3 pounds due to the weight of the bar), the deflection was 0.1001 inch, and the bar was held at this deflection and the decrease of resistance observed. In 25 minutes it had become 999 pounds; in 1 hour 40 minutes, 991 pounds; in 4 hours 35 minutes, 987 pounds, and in 5 hours 20 minutes, 987 pounds. The set was then found to be 0.007 inch under the weight of the bar itself.

Restoring the last-observed load, the deflection was 0.0991 inch, and the original load of 1,003 pounds increased it to 0.1003 inch.

A second trial of the same bar under a load of 1,603 pounds gave a

* Mr. E. H. Hewins has informed the writer since the publication of that paper that he has detected simultaneous "flow" and "exaltation of the elastic limit" in iron.

† Built for the Mechanical Laboratory of the Stevens Institute of Technology.

flection of 0.2548 inch, and a set, on removal, of 0.1091 inch. Re-
oring the load, the deflection became 0.287 inch, and the resistance to
xion decreased in 6 hours 3 minutes from 1,603 to 1,457 pounds, at
nich latter time the set was found to be 0.1451 inch. Restoring the
ad of 1,457 pounds, the deflection was 0.2863 inch, and the original
ad, 1,603 pounds, being brought upon it, its deflection increased to
3016 inch, an increase nearly 20 per cent. above the original deflection.
In the first trial the loss of stiffness, as measured by the decrease of
ort to straighten itself, and which is here taken to measure the *rate of*
, is seen to have been nearly proportional to the time at first, becoming
nstant after 4½ hours. On the second trial, after a considerable set,
oduced by a heavy load, the set became constant after about one hour,
d so remained to the end of the trial.

No. 655 was a bar of Queensland tin, received* from the Commissioner
that country at the Centennial Exibition, and which was found to
remarkably pure. A load of 100 pounds gave a deflection of 0.2109
ch, and produced a set of 0.1753 inch. The same load restored de-
cted the bar 0.2415 inch, which deflection being retained, the effort to
gain the original shape decreased in one minute from 100 to 70 pounds,
3 minutes to 62, and in 8 minutes to 56 pounds. The original load of
0 pounds then brought the deflection to 0.3033 inch, nearly 50 per cent.
ore than at first

A bar, No. 599, of copper-zinc alloy, similarly tested, deflected 0.5209
ch under 1,233 pounds, and took a set of 0.2736 inch after being held
that deflection 15 minutes, the effort falling meantime to 1,137 pounds.
storing the load of 1,137 pounds, the deflection became 0.5131 inch,
d the original load of 1,233 pounds brought it to 0.5456 inch. The
r was now held at this deflection and the set gradually took place,
e effort falling in 15 minutes to 1,133 pounds (4 per cent. more than
the first observation), in 22 minutes to 1,093, in 46 minutes to 1,063,
63 minutes to 1,043, in 91½ minutes to 1,003, and in 118 minutes to 911
unds, at which last strain the bar broke 3 minutes later, the deflec-
n remaining unchanged up to the instant of fracture. This remarka-
e case has already been referred to in an earlier paper,† when treating
the effect of time in producing variation of resistance and of the elastic
uit.

Nos. 561, copper-tin, and 612, copper-zinc, were compositions which be-
ved quite similarly to the iron bar at its first trial, the set apparently
coming nearly complete in the first after 1 hour, and in the second
er 3 or 4 hours.

In all of these metals, the set and the loss of effort to resume the
ginal form were phenomena requiring time for their progress, and in
, except in the case of No. 599—which was loaded heavily—the change
adually became less and less rapid, tending constantly toward a
ximum.

So far as the observation of the writer has yet extended, the latter is
ays the case under light loads. As heavier loads are added, and the
ximum resistance of the material is approached, the change continues
progress longer, and, as in the case of the brass above described, it
y progress so far as to produce rupture, when the load becomes heavy,
he metal does not belong to the "iron class." The brass broke under
tress 25 per cent. less than it had actually sustained previously.

There is no evidence that iron or steel ever exhibits this treacherous
d exceedingly dangerous behavior; but, on the contrary, it seems

* By the Mechanical Laboratory of the Stevens Institute of Technology.
† Vol. v, page 205.

always to carry a load, once borne, however near the maximum it may be. This difference is here quite as marked as in the experiments previously reported upon the elevation and the depression of the elastic limit by strain; and no one can fail to note the value in construction of this quality of that metal which is the chief reliance of the engineer in nearly every branch of his art. These principles will find numberless applications in the practice of every member of the profession.

The records are herewith presented, and the curves representing them shown in the Plate.

RECORDS OF EXPERIMENTS ON RATE OF SET OR DECREASE OF RESISTANCE AND INCREASE OF SET OF METALS, WITH TIME.

Bars 1 inch square; 22 inches between supports.

Time.	Load.	Loss of load.	Deflection.	Set.
	No. 648.—Wrought iron.			
	First trial.			
Minutes.	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*
.....	1,003	.....	0.0995	.....
.....	3	.....	.....	0.0049
.....	1,003	.....	0.1001	.....
25	999	4	0.1001	.....
100	991	12	0.1001	.....
275	987	16	0.1001	.....
320	987	16	0.1001	.....
320	3	.....	.....	0.007
322	987	.....	0.9910	.....
322	1,003	.....	0.1003	.....
.....	2,720	.....	2.6400	.....
	Second trial.			
.....	1,003	.....	2.2548	.....
	No. 561.—27.5 parts copper, 72.5 parts tin.			
.....	160	.....	0.0696	.....
.....	5	.....	.....	0.0145
.....	160	.....	0.072	.....
1	154	6	0.072	.....
3	150	10	0.072	.....
2,640	104	56	0.072	.....
4,140	100	60	0.072	.....
.....	5	.....	.....	0.04
.....	100	.....	0.0763	.....
.....	160	.....	0.0970	.....
.....	320	.....	0.2200	Broke.
	No. 599.—10 parts copper, 90 parts zinc.			
.....	1,233	.....	0.5209	.....
15	1,137	.....	0.5209	.....
.....	3	.....	.....	0.2736
.....	1,137	.....	0.5131	.....
.....	1,233	.....	0.5456	.....
15	1,133	100	0.5456	.....
28	1,093	140	0.5456	.....
40	1,070	163	0.5456	.....
46	1,063	170	0.5456	.....
63	1,043	190	0.5456	.....
77.5	1,023	210	0.5456	.....
91.5	1,003	230	0.5456	.....

Time.	Load.	Loss of load.	Deflection.	
Minutes.	*Pounds.*	*Pounds.*	*Inches.*	
.....	3	.....	.....	
.....	1,603	.....	0.287	
1	1,521	82	0.287	
2	1,493	110	0.287	
3	1,483	120	0.287	
23	1,463	140	0.287	
53	1,461	142	0.287	
133	1,459	144	0.287	
193	1,457	146	0.287	
363	1,457	146	0.287	
363	3	.....	.....	
.....	1,457	.....	0.2863	
.....	1,603	.....	0.3016	
.....	2,720	.....	2.6400	
96.5	993	240	0.5456	
118	911	322	.....	
121	911	326	.....	
	No. 612.—47.5 parts copper, 52.5 parts tin.			
.....	800	.....	0.3332	
.....	3	.....	.....	
.....	800	.....	0.3366	
5	790	10	0.3366	
25	778	22	0.3366	
120	766	34	0.3366	
480	756	44	0.3366	
1,320	751	49	0.3366	
.....	3	.....	.....	
.....	751	.....	0.3364	
.....	800	.....	0.3490	
.....	1,100	.....	.....	
	No. 655.—Queensland tin.			
.....	100	.....	0.2109	
.....	3	.....	.....	
.....	100	.....	0.2415	
1	70	30	0.2415	
3	62	38	0.2415	
8	56	44	0.2415	
.....	100	.....	0.3033	
.....	150	.....	Bent rapidly.	

SECTION II*.—*The observed increase of deflection under static load.*—In the preceding section the writer presented results of an investigation made† to determine the time required to produce "set" in metals belonging to the two typical classes, which exhibit, the one an exaltation and the other a depression of the elastic limit under strain.

* Prepared November, 1876.

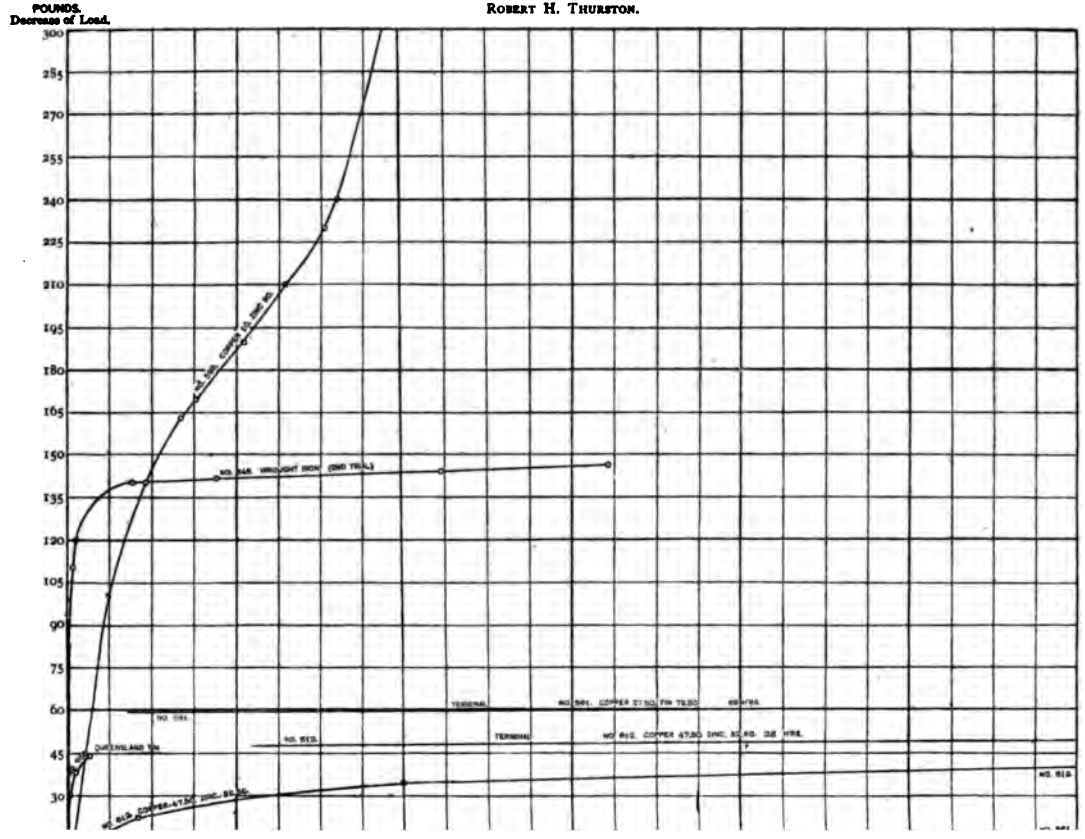
† In the Mechanical Laboratory of the Stevens Institute of Technology.

PLATE VII.

DECREASE OF RESISTANCE WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OF SET OF BARS, 1 INCH SQUARE 22 INCHES BETWEEN SUPPORTS.

ROBERT H. THURSTON.



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he experiments there described were made by means of a testing-
hine, in which the test-piece could be securely held at a given degree
listortion, and its effort to recover its form measured at intervals,
il the progressive loss of effort could no longer be detected, and until
as thus indicated that set had become complete.
he deductions were:
hat in metals of all classes under light loads this decrease of effort
rate of set become less and less noticeable until, after some time, no
her change can be observed, and the set is permanent.
hat in metals of the "tin class," or those which had been found to
ibit a depression of the elastic limit with strain, a heavy load, *i. e.*,
oad considerably exceeding the proof strain, the loss of effort con-
ued until, before the set had become complete, the test-piece yielded
irely.
And that in the metals of the "iron class," or those exhibitingan ele-
ion of elastic limit by strain, the set became a maximum and perma-
nt, and the test-piece remained unbroken, no matter how near the
ximum load the strain may have been.
The experiments here described were conducted with the same object
those above referred to. In these experiments, however, the load,
stead of the distortion, was made constant, and deflection was allowed
progress, its rate being observed, until the test-piece either broke
der the load or rapidly yielded, or until a permanent set was pro-
ced. It will be seen that the results of these experiments are in strik-
g accordance with those conducted in the manner previously described.
ey exhibit the fact of a gradually-changing rate of set for the several
ses of light or heavy loads, and illustrate the striking and important
stinctions between the two classes of metals even more plainly than
e preceding. The accompanying record and the strain-diagrams,
ich are its graphical representation, will assist the reader in com-
hending the method of research and its results. All test-pieces
re of one-inch square section, and loaded at the middle. The bear-
gs were 22 inches apart.
No. 651 was of wrought iron from the same bar with No. 648, already
scribed.* This specimen subsequently gave way under a load of 2,587
unds. Its rate of set was determined at about 60 per cent. of its ulti-
te resistance, or at 1,600 pounds. Its deflection, starting at 0.489
h, increased in the first minute 0.1047; in the second minute, 0.026;
the third minute, 0.0125; in the fourth minute, 0.0088; in the fifth
nute, 0.0063; and in the sixth minute, 0.0031 inch; the total de-
tions being 0.5937, 0.6197, 0.6322, 0.641, 0.6473, and 0.6504 inch.
the succeeding 10 minutes the deflection only increased 0.0094 inch,
to 0.6598 inch, and remained at that point without increasing so
ch as 0.0001 inch, although the load was allowed to remain 344
nutes untouched. The bar had evidently taken a permanent set, and
seems to the writer probable that it would have remained at that
flection indefinitely, and have been perfectly free from liability to
cture for any length of time.
This bar finally yielded completely, under a load of 2,589 pounds, de-
cting 4.67 inches.
No. 479 was a copper bar containing 3¾ per cent. of tin. Its behavior
y be taken as typical of that of the whole "tin class" of metals, as
e preceding illustrates the behavior of the "iron class" under heavy
ds. It was subjected to two trials, the one under a load of 700 and
e other of 1,000 pounds, and broke under the latter load, after having

* Vol. v, page 208.

sustained it 1¼ hours. The behavior of this bar will be considered especially interesting, if its record and strain-diagram are compared with those of No. 599, previously given, which latter specimen broke after 121 minutes, when held at a constant deflection of 0.5456 inch; its resistance gradually falling from an initial amount of 1,233 pounds, to 911 pounds at the instant before breaking.

This bar, No. 479, was loaded with 700 pounds "dead weight," and at once deflected 0.441 inch. The deflection increased 0.118 inch in the first five minutes, 0.024 in the second 5 minutes, 0.018 in the second 10 minutes, 0.17 in the fourth, 0.012 in the fifth, and 0.008 inch in the sixth 10-minute period, the total set increasing from 0.441 to 0.65 inch. The record and the strain-diagram show that at the termination of this trial the deflection was regularly increasing. The load was then removed and the set was found to be 0.524 inch, the bar springing back 0.126 inch on removal of the weight.

The bar was again loaded with 1,000 pounds. The first deflection which could be measured was 3.118 inches and the increase at first followed the parabolic law noted in the preceding cases, but quickly became accelerated; this sudden change of law is best seen on the strain-diagram. The new rate of increase continued until fracture actually occurred, at the end of 1¼ hours, and at a deflection of 4.506 inches.

This bar was of very different composition from No. 599; it is a member of the "tin class," however, and it is seen, by examining their records and strain-diagrams, that these specimens, tested under radically different conditions, both illustrate the peculiar characteristics of the class, by similarly exhibiting its treacherous nature.

No. 504 was a bar of tin containing about 0.6 per cent. of copper—the opposite end of the scale—and exhibited precisely similar behavior, taking a set of 0.323 inch under 110 pounds and steadily giving way and deflecting uninterruptedly until the trial ended at the end of 1,250 minutes, over 21 hours. This bar, subsequently, was, by a maximum stress of 130 pounds, rapidly broken down to a deflection of 8.11 inches.

No. 501 presents the finest illustration yet entered in the record book of the Mechanical Laboratory of the Stevens Institute of Technology. The test extended over nearly 2½ days under observation, and then left for the night, was found next morning broken. The time of fracture is therefore unknown, as is the ultimate deflection. The record is, however, sufficient to determine the law, and the strain-diagram is seen to be similar to that of the second test of No. 479, exhibiting the same tendency to the parabolic shape and the same change of law and reversal of curvature preceding final rupture, and illustrates even more strikingly the fact that this class of metals is not safe against final rupture, even though the load may have been borne a considerable time, and have apparently been shown, *by actual test*, to be capable of sustaining it. A strain-diagram of each of the latter two bars is exhibited on a reduced scale to present to the eye more strikingly this important characteristic.

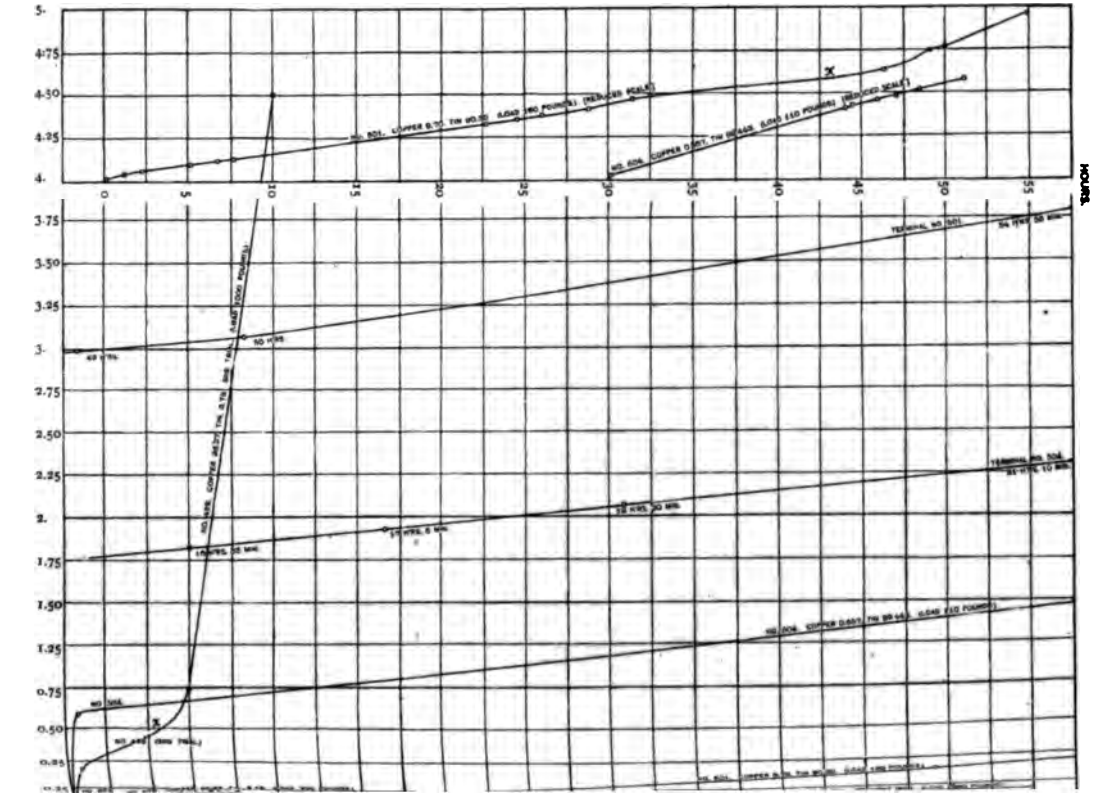
A comparison of the records and the strain-diagrams with those of Section I, in illustration of the behavior of the two classes of metals under constant deflection, is most instructive. The light thus thrown upon the phenomena of distortion and fracture may be of great service to all who are engaged in construction. It will be necessary to make many experiments to determine under what fraction of their ultimate resistance to rapidly applied and removed loads, the members of the "tin class"—the viscous metals—will be safe under static permanent loads. Their behavior under shocks of various intensities remains also

PLATE VIII

INCREASE OF DEFLECTION WITH TIME IN TRANSVERSE TESTS OF BARS OF METAL.

RATE OF SET OF BARS, 1 INCH SQUARE 22 INCHES. BETWEEN SUPPORTS.

ROBERT H. THURSTON.



determined. The most probable and most satisfactory conclusion h seems likely to be finally reached is, perhaps, that the "iron " of metals are capable of carrying indefinitely any load which have once borne, and that, in some manner—by the relief of in- l strain as suggested by the writer* or by some other process—their under a load renders them, as time goes on, more and more safe r that load.

RD OF EXPERIMENTS WITH DEAD LOADS TO DETERMINE THE INCREASE OF DEFLECTION WITH TIME, OR RATE OF SET.

Bars, 1 inch square; 22 inches between supports. Load applied at the middle.

e.	Deflection.	Increase.	
		Difference.	Total.
No. 651.—WROUGHT IRON.			
	Load, 1,600 pounds.		
tes.	*Inches.*	*Inches.*	*Inches.*
0	0. 4890	.....	.....
1	0. 5937	0. 1047	0. 1047
2	0. 6197	0. 0260	0. 1307
3	0. 6322	0. 0125	0. 1432
4	0. 6410	0. 0088	0. 1520
5	0. 6473	0. 0063	0. 1583
6	0. 6504	0. 0031	0. 1614
16	0. 6598	0. 0094	0. 1708
14	0. 6598	0. 0000	0. 1708

mum load, 2,589 pounds; maximum deflec- 7 inches.

Time.	Deflection.	Increase.	
		Difference.	Total.
Minutes.	*Inches.*	*Inches.*	*Inches.*
30	0. 618	0. 017	0. 177
40	0. 630	0. 012	0. 189
50	0. 642	0. 012	0. 201
60	0. 650	0. 008	0. 209
Set.	0. 524	.....	.....
	Second trial.—Load, 1,000 pounds.		
0	3. 118	.....	.....
5	3. 540	0. 422	0. 422
15	3. 660	0. 120	0. 542
45	4. 104	0. 442	0. 984
75	7. 634	3. 522	4. 506

Bar broke under 1,000 pounds.

)4.—0.557 PARTS COPPER, 99.443 PARTS TIN.

Load, 110 pounds.

0	0. 323	.....	.....
5	0. 406	0. 083	0. 083
15	1. 945	1. 539	1. 622
45	2. 005	0. 059	1. 681
65	2. 138	0. 134	1. 815
25	2. 248	0. 110	1. 925
0	2. 378	0. 130	2. 055
0	2. 626	0. 248	2. 303

mum load, 130 pounds; maximum deflec- 1 inches.

No. 501.—9.7 PARTS COPPER, 90.3 PARTS TIN.

Load, 160 pounds.

0	1. 294	.....	.....
10	1. 319	0. 025	0. 025
70	1. 463	0. 144	0. 169
130	1. 530	0. 067	0. 236
310	1. 691	0. 161	0. 397
400	1. 766	0. 075	0. 472
460	1. 811	0. 045	0. 517
1, 360	2. 534	0. 723	1. 240
1, 475	2. 697	0. 163	1. 403
1, 565	2. 782	0. 085	1. 488
1, 730	2. 938	0. 156	1. 644
1, 880	3. 136	0. 198	1. 842
2, 780	3. 798	0. 662	2. 504
2, 940	4. 274	0. 476	2. 980
3, 000	4. 349	0. 075	3. 055
3, 295	5. 097	0. 748	3. 803

Bar left under strain at night and found broken in the morning.

79.—96.27 PARTS COPPER, 3.73 PARTS TIN.

Load, 700 pounds.

0	0. 441	.....	.....
5	0. 559	0. 118	0. 118
0	0. 583	0. 024	0. 142
0	0. 601	0. 018	0. 160

e law of deflection and of rate of set, as illustrated graphically by train-diagrams given in this and in the preceding paper, is ex- ed for the lighter loads by equation of the form

$$Y = AT - BT^2$$

ich Y is the deflection or the set, both quantities varying together s case, and T is the time; A and B being constant coëfficients to termined for special cases.

re makers have learned that newly-made wire is considerably weaker than simi- e which has been so long made as to afford time for relief, by flow, of the internal ng introduced by the process of drawing.

For heavy loads, after the first sudden deflection and set, the equation is seen to be

$$Y = AT$$

in which for iron, $A = \frac{1}{Y}$ and for the tin-class A is a constant multiplier up to a limit x, Nos. 501, 479, at which it varies as some new function of the time.

The values of constants for the various metals remain to be determined. The question whether this change in the value of the modulus of rupture, as exhibited in the preceding section, and of the value of the quantity representing in the usual formulas the amount of deflection, is due to a change in the modulus of elasticity, to simple flow, or to a variation of cohesive force, remains to be considered.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

[Incorporated 1852.]

DISCUSSION AT THE SEVENTH ANNUAL CONVENTION.*

FLEXURE OF BEAMS.

Mr. ROBERT H. THURSTON—Referring to "Resistances of beams to flexure":—†

1°. I agree fully with General Barnard in considering the formula of Navier, and those in common use as based upon them, as well as the arguments of Decomble sustaining the former, as not well supported by the results of experiment, except in a few special cases.

2°. The ordinary theory, and its resulting equations, in which the resistances of particles to compression and to extension are proportional to their distance from the neutral surface, are apparently sufficiently correct up to that limit of flexure at which the exterior sets of particles on the one side or on the other are forced beyond the elastic limit.

3°. With absolutely non-ductile materials, or materials destitute of viscosity, fracture occurs at this point. But, with ordinary materials, and notably with good iron, low steel, and all of the useful metals and alloys in common employ, rupture does not then take place.

4°. The exterior portions of the mass are compressed on the one side, offering more and more resistance nearly, if not quite, up to the point of actual breaking, which breaking may only occur long after passing the elastic limit. On the other side, the similar sets of particles are drawn apart, passing the elastic limit for tension, and then resisting the stress with approximately constant force, "flow" occurring until that limit of flow is reached, and rupture takes place.

5°. Fracture may occur under either of several sets of conditions.

A. The material may be absolutely brittle. (*a.*) In this case the elastic limit and the limit of rupture coincide for both simple tension and simple compression. The piece will break with a snap when, under flexure, either limit is reached. (*b.*) Or, it may happen that the limit is reached simultaneously on both sides.

B. The material may be slightly viscous. (*a.*) The flexure of the piece will produce compression or extension, or both, beyond the elastic

* Referring to Record of Experiments showing the character and position of Neutral Axes, as shown by polarized light, L. Nickerson, vol. iii, page 31; and to Resistance of Beams to Flexure, J. G. Barnard, vol. iii, page 123.

† Vol. iii, page 123.

limit before rupture, giving three sets of conditions to be expressed by the formula. (*b.*) The increase of resistance after passing the elastic limit will not be similar for both forms of resistance, and each substance will probably be found characteristically distinguishable from every other. (*c.*) It would appear from experiments already familiar, that the resistance to compression will frequently increase in a very high ratio as compared with that to extension, thus swinging the neutral surface toward the compressed side, and probably sometimes approximately to the limiting surface, with very hard and friable substances, thus bringing about something like a correspondence with "Galileo's theory." This, I presume, does not often happen.

C. The material may be very ductile or viscous.* (*a.*) In this case the phenomena of flexure and rupture will be as last described, but of exaggerated extent and importance. (*b.*) The resistances to extension and to compression as developed in this case will be approximately, or accurately, those observed in experiments producing rupture by direct tension and by direct compression. The neutral surface will be determined in position by the ratio of these ultimate resistances.

6°. Proposition 1, of Decomble, as rendered by General Barnard,† therefore, may or may not be true for any individual case, and it cannot be true for all materials. Proposition 2 is, I think, probably correct, it being understood that the effect of "flow" in producing modification of the coefficients of elasticity and of rupture is comprehended. Proposition 3 is, I should say, certainly incorrect for ductile substances.

Decomble is, therefore, in error in claiming that Navier's theories, narrow and inflexible as are their conditions, explain "all phenomena" of flexure and rupture, or that it can always give us correct moduli of rupture, or that it is in "complete harmony" with any but a narrow range of practice.

7°. The statement that "any load, however small," is "capable of producing rupture, providing that the trial is sufficiently prolonged," I have long since shown, by experiment (which has been published in this country and in Europe),‡ to be quite the reverse of the truth in the case of iron, steel, &c. The fact, as shown by the *fac-simile* strain-diagrams illustrating these papers, being that *static stress, less than that producing rupture, but greater than that corresponding with the elastic limit, produces actual increase of resisting power.* This fact has since been proven by other investigators and by quite independent methods of research.

8°. I have also shown in those experimental investigations that the converse fact exists, that *distortion, rapidly produced, causes an actual decrease of resisting power.* Strain-diagrams were given illustrating this fact very strikingly.

9°. This variation of resistance with variation of the method of rupture introduces another element of uncertainty into "Navier's theory," as well as into all formulas yet constructed. This element must remain until experiment has indicated a measure of it and the form of the function expressing its law, and thus enable us to construct a correct formula.

10°. Referring to the remarks of General Barnard which follow the paper under discussion,§ we may find in the phenomena just considered a reason for the fact, remarked by him, that "beams fractured by shot

* It is to be remembered that viscosity and high cohesive force may coexist, as shown by Prof. Henry and Mon. Tresca.

† Vol. iii, page 123.

‡ Transactions, vol. ii, page 239; vol. iii, page 12, &c.; Journal of the Franklin Institute, 1874; Van Nostrand's Engineering Magazine, 1874; London Engineering, 1873; Practical Mechanics' Magazine, 1874; *Dingler's Polytechnisches Journal*, 1875.

§ Vol. iii, page 127.

did not resist anything like so much" as those broken under the slow and steady action of the hydraulic press.

11°. The assumption that resistances vary each way from the neutral surface proportionally with their distance from that surface is, when coupled with a rejected hypothesis of Navier, nevertheless, not far from the truth in special cases, as may be shown by proper mathematical treatment and comparison with results obtained experimentally.

12°. Mr. William Kent made this comparison for cast and wrought iron and for ash. The results of analysis and of experiment give the following values of the R in the ordinary formula:*

$$M=\tfrac{1}{6}\,R\,B\,D^2 \qquad (1)$$

for a beam fixed at one end, loaded at the other:

	Cast iron.	Wrought iron.	Ash.
R (theoretical)	32,280	60,000	[illegible]
R (experimental)	35,000	60,000	[illegible]

13°. This remarkable approximation is thus derived: Suppose a fixed beam, Fig. 5, with loaded extremity, the force P being a measure of the weight W, and the beam having a depth D, a breadth unity, and a neutral surface situated at a distance Y from the superior surface of the beam. Representing the resistances graphically by the triangles T N, C N; their measures in tension and compression are respectively $\frac{1}{2}$ T N, $\frac{1}{2}$ C N, and their moments are $\frac{1}{2}$ T N $\times\frac{2}{3}$ Y$=\frac{1}{3}$ T Y^2, and $\frac{1}{2}$ C N$\times\frac{2}{3}$ (D$-$Y)$=\frac{1}{3}$ C (D$-$Y)^2. An early hypothesis of Navier, which seems to have been entirely abandoned by him subsequently, and which has not been accepted by subsequent writers on the subject, makes these moments equal. Assuming this to be correct,

Fig. 5.

$$T\,Y^2=C\,(D-Y)^2 \qquad (2)$$

$$\text{and } \frac{C}{T}=\frac{Y^2}{(D-Y)^2} \qquad (3)$$

and, from this expression, we may find the position of the neutral surface, as determined by the assumed conditions. Then, letting B=the breadth of the beam,

$$W\,L=\tfrac{1}{3}\,B\,[T\,Y^2+C\,(D-Y)^2]=\tfrac{1}{6}\,R\,B\,D^2 \qquad (4)$$

in which latter expression R is the modulus of rupture, and its value can be found when C and T are known. It will always be of a value intermediate between T and C.

14°. The following are the data and results for the three cases taken; the results are well worthy of examination and record:

	T	C	B	D	L	Y	D$-$Y	WL	R
Cast iron	16,000	96,000	1	1	1	0.71	0.29	5,380	[illegible]
Wrought iron	60,000	60,000	1	1	1	0.5	0.5	10,000	[illegible]
Ash timber	17,200	9,000	1	1	1	0.42	0.58	2,920	[illegible]

* Wood on Resistance of Materials.

5°. The common theory of rupture, as it is defined by Professor Wood, confessedly far from correct, and, as shown at the beginning of these narks, the neutral surface must vary in position, and cannot invariably ss through the center of gravity of section. It would seem that such ncidence of position, when occurring at all, is simply a matter of in- ental concurrence of conditions. I therefore consider the criticism General Barnard to be just in this point.

6°. The accurate mathematical expression of the phenomena of ture and rupture, as already remarked, must be vastly more compre- nsive and flexible and more facile of application than any yet pro- ed. As I have shown, it is not sufficient that both R_1 and R_2—*i. e.*, h T and C—appear in the formulas, as proposed by Decomble. The l value of these quantities, as there appearing, must vary as some ction of distance from the neutral line, while the position of the neu- l line must itself vary with both the value of T and C in different es, and with their change of value in the same beam, as flexure pro- sses and after rupture commences. These variable functions must be taken into account and comprised in the general expression for moment resisting fracture.

The characters of these functions, however, are unfortunately not yet ertained, and it is only after experiments in which the moment of re- ance is accurately measured during every stage of fracture, and completely that the strain-diagram of the experiments can be graph- lly given, or its equation constructed, that we can obtain their values. s has, as yet, been done in but few cases, as in some experiments of dgkinson, in the work of Styffe, and in experiments made by Rodman.

7°. It does not necessarily follow that the formulas finally resulting st be either complex or inconvenient of application. Simple expres- ns will, at least, be found for special cases of simple character, which l serve every purpose of the engineer.

8°. It is also true, as remarked by Professor Wood, and as known by ry engineer, that the phenomena of flexure within admissible limits much less complex and much less difficult of manipulation than those rupture, or than those resulting in serious permanent distortion. nce, it is true that ordinary engineering practice is not placed at h a serious disadvantage as these defects of the theory of strain ght seem to indicate.

9°. In common with every member of the profession, I am called on to admit the great services rendered us by Navier in the splendid rk done by him at *l'Ecole des Ponts et Chaussées*, in establishing a ory of engineering, as well as in working up a theory of rupture, and esire to acknowledge those services, while declining to admit absolute uracy in his theories. They were constructed at a time when science s apparently divorced from the practice of engineering, and when his vices in securing a genuine union were most invaluable. He must ays be regarded as one of the great leaders in our profession.

I would unite with General Barnard in his remarks, relative to the empt of Navier's pupil, Decomble, to retain the theory while mod- ng the formulas of Navier: "If by discarding a coefficient founded on an imaginary coefficient of elasticity, and the introduction of dis- ct and independent factors, symbolic of resistance to rupture by com- ssion and extension, it is shown that the Navier formula can be de reliable, an important service has been rendered to engineering nce."*

I would myself add that the discovery and the mathematical expres-

* Vol. iii, page 126.

sion of the varying functions which I have described, and the establishment of formulas of application embodying the facts of the variation of the coefficient of elasticity, of that of the module of resistance of rupture by tension and compression, and in the position of the neutral surface, which are still, as previously, essential but unknown elements of a correct theory of strain; all of these yet remain to compensate some skillful experimenter and expert analyst. Their determination would earn for their fortunate discoverer higher distinction than ever won by either Coulomb or Navier.

ARLIER RESEARCHES ON THE PROPERTIES OF THE METALLIC ALLOYS.

UED BY COMMITTEE ON METALLIC ALLOYS OF THE UNITED STATES BOARD, APPOINTED TO TEST IRON, STEEL, AND OTHER METALS.

RESEARCHES ON THE METALLIC ALLOYS.

INTRODUCTION.

The writer, before making the researches directed by the Committee Metallic Alloys, and before entering upon the series of experiments the characteristics of alloys, has, as a proper introduction to the rk, made a somewhat exhaustive examination of the records of earlier periments made in this direction, with a purpose, both to save useless or in repeating that part of the work which has already been done investigators of acknowledged authority, and to make the report the committee more complete by incorporating a synopsis of the ords of researches of others. A large number of papers by various ters in the different American and foreign scientific journals have n reviewed, as well as articles on the alloys in encyclopedias, dicnaries of chemistry, &c. In all cases where practicable, the original moirs were consulted. A list of the authorities and papers will be nd in the appendix.

The result of this preliminary investigation has been to reveal a vast ount of information on the chemical and physical properties of the oys; but such information is widely scattered, and authorities do not ays agree. Some experiments have been made upon alloys made n the impure commercial metals, others from metals rendered chemlly pure for the purpose. As a necessary consequence, the results of se experiments differ. Again, the apparatus used has not always n of the same degree of accuracy, and this has produced another se of disagreement. These differences, however, are usually slight. e greatest difficulty in obtaining information on the subject is not t there is not enough written, but that what is written is so widely ttered as to be accessible to but few.

This deficiency it will be endeavored in some degree to remedy, by cing the results obtained by various experimenters side by side.

We shall consider, in the first place, the properties of the alloys in neral, and then discuss the different alloys in order, beginning with oys of two metals only, and then taking those of three or more.

PROPERTIES OF THE ALLOYS IN GENERAL.

It is evident that alloys, being composed of metallic bodies, will possess all the physical and chemical characteristics of metals; they have the metallic luster, are more or less ductile, malleable, elastic, and sonorous, and conduct heat and electricity with remarkable facility. In retaining these properties, however, the compound is so modified in some of its properties, that it often does not resemble either of its constituents, and might, consequently, be regarded as a new metal, having characteristics peculiar to itself. This is especially the case with those which are used in the arts. It would almost seem that there is no department of the arts, requiring the use of metals, for which an alloy may not be prepared, possessing all the requisite qualities when these are not found in the original metals.* The physical properties of an alloy are often quite different from those of its constituent metals. Thus copper and tin, mixed in certain proportions, form a sonorous bell-metal, possessing properties in which both metals are deficient; in another proportion they form speculum metal, which is as brittle as glass, while both of the constituent metals are ductile. It is impossible to predict from the character of two metals what will be the character of an alloy formed from given proportions of each. In most cases, however, it will be found that the hardness, tenacity, and fusibility will be greater than the mean of the same properties in the constituents, and sometimes greater than in either; while the ductility is usually less, and the specific gravity is sometimes greater and sometimes less.† The color is not always dependent upon the colors of the constituent metals, as is shown by the brilliant white of speculum metal, which contains 67 per cent. of copper.

Very slight modifications of proportions often cause very great changes in properties. M. Bischof‡ states that he can detect the deteriorating effect of one part tin upon 10 million parts of pure zinc, and the writer has found half of a per cent. of lead to reduce the strength of good bronze nearly one-half and to affect its ductility to an almost equal extent.

It is not a matter of indifference in what order the metals are melted in making an alloy. Thus, if we combine 90 parts of tin and 10 of copper, and to this alloy add 10 of antimony; and if we combine 10 parts of antimony with 10 of copper, and add to that alloy 90 parts of tin, we shall have two alloys chemically the same, but in other respects—fusibility, tenacity, &c.—they totally differ. In the alloys of lead and antimony, also, if the heat be raised in combining the two metals much above their fusing points, the alloy becomes harsh and brittle.

Some metallic alloys are much more easily oxidizable than the separate metals. An alloy of tin and lead heated to redness takes fire and continues to burn for some time.§

In regard to certain physical properties, Matthiessen‖ remarks that the metals may be divided into two classes:

Class A.—Those metals which impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

Class B.—Those metals which do not impart to their alloys their physical properties in the proportion in which they themselves exist in the alloy.

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* Muspratt's Chemistry, vol. 1, p. 533.
† Ure's Dictionary, vol. 1, pp. 46–50.
‡ British Assoc. Reports, 2, 1870, pp. 209, 210.
§ Ure's Dictionary, vol. 1, p. 49.
‖ Jour. Chem. Soci., vol. 5, 1867, pp. 201–220.

The metals belonging to class A are lead, tin, zinc, and cadmium; and ose belonging to class B, in all probability, all the rest.

The *physical properties* of alloys may be divided into three classes:

I. Those which in all cases are imparted to the alloy approximately the ratio in which they are possessed by the component metals.

II. Those which in all cases are not imparted to the alloy in the ratio which they are possessed by the component metals.

III. Those which in some cases are and in others are not imparted to e alloy in the ratio in which they are possessed by the component etals.

As types of the first class, specific gravity, specific heat, and expan- on due to heat may be taken; as types of the second class, the fusing ints and crystalline form; and as types of the third class, the conduct- g power for heat and electricity, sound, elasticity, and tenacity.

THE CHEMICAL NATURE OF ALLOYS.

The chemical nature of alloys has long remained a disputed point among ientists. The question "Are alloys definite chemical compounds, solu- ns, or mechanical mixtures?" is not easily answered. Several authors ve their views and describe their methods of making experiments to ttle this question, but there still remains a wide difference of opinion regard to it. Most writers now agree, however, in considering some oys as chemical compounds and others as mixtures, but they differ as whether any particular alloy is the one or the other. Thus Calvert d Johnson* consider the tin-copper alloys definite compounds, while tthiessen† claims that they are "solidified solutions of one metal in allotropic modification of the other." Muspratt‡ says:

Many alloys consist of simple elements in definite or equivalent proportions, while ers are produced from compound bodies, and often the components do not exist in ratio of their chemical equivalents. Metals, in forming alloys, do not, however, ubine indiscriminately with one another; the union is governed by the greater nities which some of them manifest for each other, just as, in the chemistry of bases l acids, a predisposing attraction determines a preference. This in some measure ves that the alloys are not mechanical mixtures, but definite chemical compounds. s remarkable that the native gold found in auriferous sands and rocks is alloyed h silver in the ratio of one equivalent of the latter to four, five, six, eight, ten, *et ra*, equivalents of the former, but the combinations never afford results indicative the metal being united in fractional parts of an equivalent.

Muspratt further says that another proof of the chemical combination sisting is, that the compound melts at a lower temperature than the an of its ingredients; but Matthiessen§ argues that this is no proof all.

Watts‖ remarks that most metals are probably to some extent capable existing in combination with each other in definite proportions; but s difficult to obtain these compounds in a separate condition, since y dissolve in all proportions in the melted metals, and do not gen- lly differ so widely in their melting or solidifying points from the tals they may be mixed with as to be separated by crystallization in definite condition.

he chemical force capable of being exerted between different metals may, as a rule, expected to be very feeble, and the consequent state of combination would there- be very easily disturbed by the influence of other forces. But in all cases of com- ation between metals, the alteration of physical properties, which is the distinctive

* Phil. Trans., 1858, p. 363.
† British Assoc. Rep., 1863, p. 47.
‡ Muspratt's Chemistry, vol. 1, p. 534.
§ British Assoc. Rep. 1863, p. 42; also, Jour. Chem. Soc., vol. 5, 1867, p. 207.
‖ Watts's Dictionary, vol. iii, p. 942.

feature of chemical combination, does not take place to any great extent. The most unquestionable compounds of metals are still metallic in their general physical characters, and there is no such transmutation of the individuality of their constituents as takes place in the combination of a metal with oxygen, or sulphur, or chlorine, &c. The alteration of characters in alloys is generally limited to the color, degree of hardness, tenacity, &c.

Messrs. Calvert and Johnson,* about the year 1860, made a long series of experiments on alloys and amalgams made with pure metals, with the hope of throwing some light upon the subject, and of solving the question "Are alloys mixtures or compounds?" They believe that they have succeeded in ascertaining: First, the influence which each additional equivalent quantity of a metal exerts on another; secondly, the alloys which are compounds and those which are simple mixtures, for compounds have special and characteristic properties, while mixtures participate in the properties of the bodies composing them. They hold that the bronze alloys are definite compounds; for each alloy has a special value of conductivity of heat, and also its own specific gravity, and its own rate of expansion or contraction; while, on the contrary, the alloys of tin and zinc are mixtures; for they conduct heat, have a specific gravity and expand according to theory, or according to the proportions of tin and zinc which compose each alloy. Calvert and Johnson's conclusions are chiefly based upon their experiments on the heat conductivity of the alloys. Later experiments, made by Matthiessen,† on the conducting power for electricity, led him to different conclusions. He experimented upon upwards of 250 alloys, all made of purified metals. The results of his investigations are published in a valuable paper, "On the Chemical Nature of Alloys," from which we transcribe the following classification of the solid alloys, composed of two metals, according to their chemical nature. The reasons for this classification are given in full in the above-named paper, but we must omit them here for want of space.

1. *Solidified solutions of one metal in another:*

The lead-tin, cadmium-tin, zinc-tin, lead-cadmium, and zinc-cadmium alloys.

2. *Solidified solutions of one metal in the allotropic modification of another:*

The lead-bismuth, tin-bismuth, tin-copper, zinc-copper, lead-silver, and tin-silver alloys.

3. *Solidified solutions of allotropic modifications of the metals in each other:*

The bismuth-gold, bismuth-silver, palladium-silver, platinum-silver, gold-copper, and gold-silver alloys.

4. *Chemical combinations:*

The alloys whose composition is represented by Sn_5Au, Sn_2Au, and Au_2Sn.

5. *Solidified solutions of chemical combinations in one another:*

The alloys whose composition lies between Sn_5Au and Sn_2Au, and Sn_2Au and Au_2Sn.

6. *Mechanical mixtures of solidified solutions of one metal in another:*

The alloys of lead and zinc, when the mixture contains more than 1.2 per cent. lead or 1.6 per cent. zinc.

7. *Mechanical mixtures of solidified solutions of one metal in the allotropic modification of the other:*

The alloys of zinc and bismuth, when the mixture contains more than 14 per cent. zinc or 2.4 per cent. bismuth.

* See list of Calvert & Johnson's papers in the appendix.

† British Assoc. Reports, 1863, pp. 37–48.

. Mechanical mixtures of solidified solutions of the allotropic modifica-ns of the two metals in one another:

Most of the silver-copper alloys.

Matthiessen, however, does not claim that the above classification is liable to exception. He was obliged to assume that some of the met- undergo a change, or are converted into an allotropic modification the presence of another metal, in order to explain some of the phe-nena which he observed, but he admits that until the allotropic modi-ations have been isolated, the assumption must remain a hypothesis. To conclud , we can only say that the question is still unsettled. From marked peculiarities of properties observed in a few of the alloys, are led to pronounce them chemical compounds. Some others, we st admit, are simple mixtures, or rather, solidified solutions. But in gard to the large majority we are still in doubt. Further experiments y throw more light on the subject, but it is probable that with the ger number of alloys it will be found impossible to discover their ex- chemical nature.

SPECIFIC GRAVITY.

The specific gravity of an alloy is rarely the mean between the densi-s of each of its constituents. It is sometimes greater and sometimes s, indicating, in the former case an approximation, and in the latter separation of the particles from each other in the process of alloying. is subject has been studied by several writers, and their published sults agree quite closely in regard to some of the alloys, but differ in gard to others. These differences may be accounted for by the differ-ces in the apparatus used by the experimenters, by the fact that some terminations have been corrected for temperature and pressure of the mosphere while others were not, but principally from the fact that veral of the alloys are liable to be very deficient in homogeneity, and at the density of the same alloy will vary according to the conditions der which it is formed, as being cast too cold or too hot, cast in iron in sand moulds, &c. A bar cast in a vertical position is apt to have greater specific gravity at the bottom of the bar than at the top. Re-ated fusion of an alloy also causes changes in its density.

It is common among authorities who publish determinations of spe-ic gravities of the alloys, to give the calculated as well as the observed ecific gravity. The calculated specific gravity is that which the alloy uld have if there were neither expansion nor condensation of the tals during the act of combination. Some writers have made a mis-te in finding the calculated specific gravity by assuming it to be the thmetical mean between the numbers denoting the two specific gravi-s, or, in other words, multiplying the percentage weight of each con-tuent by its specific gravity, adding the results and dividing by 100. e specific gravities should be calculated from the volumes and not m the weights. Dr. Ure* gives the correct rule as follows: Multiply sum of the weights into the products of the two specific gravity mbers for a numerator, and multiply each specific gravity number o the weight of the other body and add the products for a denomina-. The quotient obtained by dividing the said numerator by the de-minator is the truly computed mean specific gravity of the alloy. Pressed in algebraic language, the above rule is—

$$M = \frac{(W + w)\, Pp}{P w + p W}, \qquad (1)$$

*Ure's Dictionary, vol. 1, p. 49.

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals. Calvert and Johnson * seem to have fallen into the error just mentioned, and the expansion and condensation of different alloys as given by them is not strictly correct. Professor Bolley has also committed the same, as shown by Matthiessen.†

The observed, or real, specific gravities of the alloys, however, published by these writers, are not affected by the error named, and they are, no doubt, worthy of acceptance.

The valuable compilation of the "Constants of Nature,"‡ published by the Smithsonian Institution, contains a full table of specific gravities of the alloys, with the names of about twenty-five authorities. Of these the principal are Mallet,§ Calvert and Johnson,‖ Matthiessen,¶ and Riche.**

The following table of the alloys whose density is greater or less than the mean of their constituents, is given by several writers:

Alloys, the density of which is greater than the mean of their constituents.	Alloys, the density of which is less than the mean of their constituents.
Gold and zinc.	Gold and silver.
Gold and tin.	Gold and iron.
Gold and bismuth.	Gold and lead.
Gold and antimony.	Gold and copper.
Gold and cobalt.	Gold and iridium.
Silver and zinc.	Gold and nickel.
Silver and tin.	Silver and copper.
Silver and bismuth.	Iron and bismuth.
Silver and antimony.	Iron and antimony.
Copper and zinc.	Iron and lead.
Copper and tin.	Tin and lead.
Copper and palladium.	Tin and lead.
Copper and bismuth.	Tin and palladium.
Lead and antimony.	Nickel and arsenic.
Platinum and molybdenum.	Zinc and antimony.
Palladium and bismuth.	

The above table is probably inaccurate in many respects. Calvert and Johnson agree with Matthiessen in giving the density of the alloys of lead and antimony as less than the mean of the constituents, and Matthiessen shows the alloys of lead and gold to have a greater density than the mean of their constituents. Some alloys of tin and gold and of bismuth and silver are shown by Matthiessen to have a greater, and some a less, density than the mean of their constituents, and the same is true of the alloys of some other metals.

FUSIBILITY.

A remarkable property of many of the alloys is their great fusibility. In nearly all cases the fusing point of an alloy is lower than the mean of its constituent metals, and in some instances, as in the so-called fusible alloys, it is lower than that of either. The cause of this fact has not been definitely ascertained. Some regard it as a proof that the alloy is a distinct chemical compound, but most authorities differ from

* Phil. Mag., 18, 1859, pp. 354–359.
† Jour. Chem. Soc., vol. 15, 1862, pp. 30, 106.
‡ Constants of Nature, published by the Smithsonian Institution, Washington, D. C., 1873.
§ Phil. Mag., vol. 21, 1842, pp. 66–68.
‖ Phil. Mag., vol. 18, 1859, pp. 354–359.
¶ Phil. Trans., 1860, pp. 177–184.
** *Comptes Rendus*, vol. 55, 1862, pp. 143–147.

s view. Matthiessen* supposes that chemical combinations may exist the fused mass, which suffer decomposition on cooling or solidifying. says that the low fusing points admit of explanation by assuming t chemical attraction between the two metals comes into play as soon the temperature rises, and the moment the smallest portions melt, n the actual chemical compound is formed which fuses at the lowest nperature, and then acts as a solvent for the particles next to it, and promotes the combination of the metals where this can take place.

n another place† Matthiessen remarks that all mixtures have a lower ing point than the mean of the substances forming the mixture; for tance, salt-water solidifies below zero, and a mixture of the chlorides sodium and potassium fuse at a lower point than the mean of the ing points of the components.

his fact, he believes, admits of explanation as follows:

> is generally admitted that matter in the solid state exhibits an excess of attraction over repulsion, while in the liquid state these forces are balanced, and in the eous state repulsion predominates over attraction. Let us assume that similar icles of matter attract each other more powerfully than dissimilar ones. It will follow that the attraction subsisting between the particles of a mixture will be er overcome by repulsion than in the case of a homogeneous body; hence mixtures ld fuse more readily than their constituents.

ome alloys have been observed to fuse at one point and solidify at a er one; for example, the tin-lead alloys, which all solidify at 181° C., the fusing point of which varies with the different proportions of component metals from 181° C. to 292° C.

oncerning these alloys, Pillichody‡ remarks as follows:

> hen the points of solidification are observed by immersing the thermometer in the ted alloy, it usually exhibits, during the passage of the mass from the liquid to solid state, two stationary points. This effect is due to the separation of one or r of the component metals, while an alloy of constant composition still remains id. This alloy corresponds to the composition Sn_3 Pb. An alloy richer in lead ld first deposit lead, and an alloy containing a larger proportion of tin would first osit tin—the alloy Sn_3 Pb remaining liquid for a longer or shorter time, and ultiely solidifying at 181° C. This temperature therefore corresponds to the lowest ting point that can be exhibited by an alloy of tin and lead, a larger proportion ither metal causing the melting point to rise.

With the exception of the alloys of tin and lead, and the fusible als, the fusing points of but few of the alloys have been determined. accurate pyrometer for temperatures above red heat is greatly ded for this purpose. The "Constants of Nature," while it has the cific gravities of several hundred alloys, gives the melting points of y six, exclusive of the fusible alloys and those of lead and tin. Mal gives the relative fusibility of the several alloys of copper and tin. l copper and zinc, and shows that their fusibility increases regularly the proportion of copper in the alloy diminishes.

ome alloys in passing from the liquid to the solid state do not change nce, but remain for some time in a pasty condition. Their temperae of solidification, therefore, cannot be distinctly recognized. This is case with an alloy of the composition Bi_2 Pb Sn_2, which is fusible in ling water, but which remains in a pasty condition through an inter of several degrees of temperature, so that it can be handled like a ster.

I. Person‖ made experiments upon the alloys Bi_3 Pb_2 Sn_2 (D'Ar-

* British Assoc. Reports, 1863, p. 42.
† Jour. Chem. Soc., vol. 5, 1867, p. 207.
‡ Jour. Chem. Soc., vol. 15, 1862, p. 30.
§ Phil. Mag., vol. 21, 1842, pp. 66-68.
‖ *Comptes Rendus*, vol. 25, 1847, pp. 444-446.

cet's alloy, fusible at 96° C), Bi_2 Pb Sn_2 (fusible in boiling water), and Bi Pb Sn_2 (fusible at 145° C.), and formed the conclusion that it is possible to assign in advance the heat necessary to fuse an alloy, if that required to fuse each of its component metals is known. He gives the formula $(160 + t)\ \delta = l$, in which t is the temperature at which fusion is effected; for example, 332° C. for lead if melted alone, but only 96° C. if melted in D'Arcet's fusible alloy; l is the expenditure of heat necessary to produce the fusion, that is, a certain number of *calories* (1 *calorie*=3.96 British thermal units) variable with t; δ is the difference of the specific heats of the liquid and solid. If t and l are known, δ can be found. In the case of tin, $t = 235$, $l = 14.3$, from which $\delta = 0.0362$. Having this value of δ, it is easy to calculate the heat necessary to melt tin at any temperature whatever, for instance at 96° C., for which we find 9.3 *cal.* Making the same calculation for bismuth and for lead we find 7.382 and 2.7 *cal.* It only remains to take these numbers in the proportion in which each metal exists in the alloy, which gives a little less than 6.3 *calories*, which differs from the number found by experiment (6 *cals.*) only 0.3 *cal.*

Nothing appears to have been written upon this branch of the subject since M. Person's paper was published, but it is probable that if the investigation was pursued further our knowledge of the causes of the remarkable fusibility of the alloys would be much increased.

M. Riche* has determined the melting points of certain alloys of tin and copper, by means of Becquerel's thermo-electric pyrometer. He obtained concordant results with the alloys Sn Cu_3 and Sn Cu_6, but with all other alloys the results differed widely among themselves.

W. C. Roberts,† chemist to the British mint, has published a series of determinations of the melting points of several alloys of silver and copper. The temperature was estimated by finding the amount of heat contained in a wrought-iron cylinder of known weight which was dropped into the melted alloy while in the furnace, and removed as soon as the mass showed signs of solidifying. The specific heats of the iron and of the alloy were the data used in the calculation. The alloy, composed of 630.29 parts of silver and 369.71 parts copper, corresponding to the formula Ag Cu, showed the lowest fusing point, or 846.8° C.; that of pure copper being 1330° C., and that of pure silver 1040° C.

LIQUATION.

Many of the alloys exhibit the phenomena of liquation, or separation of the mass of melted metal in the act of solidification into two or more alloys of different composition. The resulting alloy or mixture of alloys is consequently deficient in homogeneity. The causes of this separation are as yet but imperfectly understood. Some observations seem to show that an alloy of constant composition and of a comparatively high fusing point solidifies first in crystals disseminated throughout the mass, while the remainder of the melted metal remains fluid for a longer time, and finally solidifies around and among these crystals. This fact would tend to prove that the first alloy solidified was a distinct chemical compound, but it has been shown that crystals of exactly the same appearance have been formed from two metals in a wide range of proportions.

The different circumstances under which the separated alloys may be formed, such as the heat of the metal when poured into the mold, and the fact of slow or of rapid cooling, are known to have some influence

* *Ann de Chim.*, vol. 30, 1873, p. 351.
† Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

on the amount of liquation, or the difference of composition of differ-
t parts of the same casting, but this influence is not exerted upon all
oys in the same direction, some alloys being affected in one way and
me in another by the same manner of treatment. The bronze alloys,
ch as gun-metal, are said to have the liquation diminished by rapid
oling. When the mass is cooled slowly, bronze castings often show in
e interior what are called spots of tin, but what are really spots of a
ite alloy of copper and tin, containing a larger percentage of tin than
e average of the whole casting. When slowly cooled, also, the bottom
the casting is often found to contain a larger percentage of copper
an the top. When cooled rapidly, however, as shown in the experi-
nts of General Uchatius* in casting cannon in chilled molds, the
uation is reduced to a minimum, and the resulting alloy is more
mogeneous.

Levol† made some experiments on the liquation of the alloys of silver
d copper, and concluded that the only homogeneous alloy of these two
tals was the one whose composition is 718.97 parts of silver and 281.07
rts of copper, corresponding to the formula $Ag_3 Cu_2$, and that all the
ers are liable to more or less liquation. It has lately been shown,
wever, by Mr. W. C. Roberts,‡ chemist to the British mint, that this
oy is only homogeneous when cooled rapidly. If the cooling is slowly
ected, its homogeneity is disturbed, the external portions being slightly
her in silver than the center.

Mr. Roberts made several determinations of the liquation of other
oys of silver and copper, and found that the arrangement of an alloy
to a great extent dependent on the rate at which it is cooled, and that
veral alloys of silver and copper are under suitable conditions as homo-
neous as Levol's alloy. The alloy of 925 parts silver and 75 parts
pper was found to be nearly homogeneous when cooled very slowly, the
mposition of the corners and center of a cube 45 millimeters on a side
owing a maximum difference of only 1.4 parts in 1,000, while the same
en cooled rapidly showed a difference of 12.8 parts in 1,000.

Col. J. T. Smith§ relates in reference to some experiments made by
n on the alloy of silver and copper containing 91⅔ per cent. of silver,
t the separation of the constituent parts of the alloy was not so much
e to the rapidity or slowness with which the heat of the fluid metal
s abstracted, as to the inequality affecting its removal from the differ-
parts of the melted mass in the act of consolidation. Thus, if a cru-
le full of the melted alloy were lifted out of the furnace and placed
the floor to cool, the surface of the melted metal within it being well
ered with a thick layer of hot ashes, the lower parts of the mass after
ad become solid would be found to contain less silver in proportion
n the upper surface.

If, on the other hand, the crucible were left to cool while imbedded in
furnace, the upper surface being exposed to the air, then the lower
rts would, after solidification, be found finer than the upper surface.

Riche‖ has made several experiments on the liquation of the alloys of
pper and tin. He remarks that to manifest the property of liquation,
s necessary to agitate the crucible containing the melted alloy, at the
ment of solidification, in order to separate the small crystals already
med. The results obtained on the last product, remaining liquid in a

* Ordnance Notes No. xl, Washington, D. C., 1875.
† *Ann de Chim.*, vol. 36, 1852, pp. 193–224.
‡ Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.
§ Proc. Roy. Socy., vol. 23, 1875, pp. 433–435.
‖ *Comptes Rendus*, vol. 67, 1868, pp. 1138–1140, and vol. 30, 1873, pp. 351–419.

mass weighing 1,000 to 1,200 grammes, showed a remarkable liquation of all the alloys of copper and tin except those corresponding to the formulae $Sn\ Cu_3$ and $Sn\ Cu_4$.

Several other alloys exhibit like phenomena to an even greater extent than those above mentioned. Matthiessen and Von Bose experimented upon alloys of lead and zinc and bismuth and zinc, melting the metals together in various proportions, and found that one end of a bar would have an excess of one metal and the other end an excess of the other. Alloys of copper and lead containing an excess of lead show a liquation in a remarkable degree, the excess of lead partly oozing out from the mass on cooling.

SPECIFIC HEAT.

The published determinations of the specific heat of the alloys are not numerous. This results not from any difficulty of making the observations, but probably because they have not been considered of such practical importance as those of other properties, and partly, also, because M. Regnault's* determinations, made in 1841, and his deductions therefrom, are accepted as final.

M. Regnault determined the specific heat of two classes of alloys: first, those which at 100° C. are considerably removed from their fusing points; and, secondly, those which fuse at or near 100° C. The specific heats of the first series were remarkably near to that calculated from the specific heats of the component metals, so that he announced the following law:

"*The specific heat of the alloys, at temperatures considerably removed from their fusing point, is exactly the mean of the specific heats of the metals which compose them.*"

The mean specific heat of the component metals is that obtained by multiplying the specific heat of each metal by the percentage amount of the metal contained in the alloy and dividing the sum of the products for each alloy by 100.

A curious fact discovered in regard to these alloys is also that the product of the specific heat of each alloy by its atomic weight is sensibly constant, varying in the whole series only from 40.76 to 42.05.

The second series of alloys, or those which fuse at a temperature at or near 100° C., show a wide divergence from the above law, the specific heats of all of these being much higher than that calculated from their constituents. The product of the specific heats by the atomic weights varied also from 45.83 to 72.97.

Matthiessen† describes a simple arrangement of the differential thermometer for the purpose of showing that the specific heat of an alloy is the same as the mean of those of its components.

EXPANSION BY HEAT.

The expansion of the alloys by heat has been examined by Messrs. Calvert and Lowe,‡ with a view to learn whether their expansion followed the law of the proportions of their components. Four series of alloys were examined, namely, those of zinc and tin, lead and antimony, zinc and copper, and copper and tin. In each case the expansion was less than that deduced by calculation from their equivalents.

Ann. de Chim., vol. 1, 1841, pp. 129–207.
†Jour. Chem. Soc., vol. 5, 1867, p. 205.
‡Chem. News, vol. 3, 1861, p. 315.

In alloys of copper with tin, it was found that where only a small quantity of tin entered into the composition of a bar, the expansion fell considerably below that of pure copper, although the tin added has a much higher rate of expansion than copper.

From experiments made by Messrs. Calvert and Lowe upon the expansion of chemically pure metals, they conclude that a very small proportion of impurity has a marked influence upon the expansion. Their results differed largely from those of other experimenters who used only the commercial metals; but when they, too, used commercial metals, the results agree.

The alloys upon which they experimented were also formed from pure metals, and on account of the difficulty of procuring these in sufficient quantity, the bars experimented on were very small, being only 60 milimeters, or less than $2\frac{1}{2}$ inches long. The apparatus used, however, as described at length in the "Chemical News", was so sensitive, that an expansion of $\frac{1}{50000}$ of an inch could readily be observed

If experiments were made upon alloys formed from the ordinary commercial metals, it would probably be found that their rate of expansion would differ considerably from that of alloys formed from pure metals.

The molecular condition of a metal was observed to have an important influence on the rate of expansion. The same will no doubt be found true in the case of alloys.

Matthiessen* states that the expansion due to heat of the metals takes part in that of their alloys approximately in the ratio of their relative volumes. He gives a table of the expansion of several alloys which tends to confirm his statement.

CONDUCTIVITY FOR HEAT.

The power of the alloys to conduct heat has been examined with great care by several experimenters. The published results are not always concordant, but the differences may be partially accounted for by the various kinds of apparatus used, and the great influence which small impurities and changes in molecular condition and crystalline form exert upon conductivity.

The conducting power for heat in an alloy is found in some cases to be the mean of the conducting power of the component metals, and in others to apparently have no relation whatever to such mean. As examples of the first case may be cited the alloys of tin and zinc and tin and lead; and of the second, the alloys of gold and silver and gold and copper. From this circumstance it has been expected that the heat-conducting power could be used as a means of determining whether an alloy is a chemical compound or a simple mixture. As before stated, however, the authorities differ widely on this point.

Messrs. Weidemann and Franz†, in 1853, made some experiments on the conducting power of the metals and of a few of the alloys, using a thermo-electroscope as an apparatus.

In 1858, Calvert and Johnson‡ made an extensive research on alloys formed from pure metals, using an apparatus of their own invention, by which the relative conducting power was shown by the rise in temperature in a given time of a given volume of water secured in a box at one end of the bar, while the other end of the bar was heated to 90° C. They claim that the method which they employed gave such consistent

* Jour. Chem. Soc., vol. 5, 1867, p. 206.
† *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.
‡ Phil. Trans., 1858, pp. 349–368.

results, that they were able to determine the influence exercised on the conducting power of the metals by the addition of 1 or 2 per cent. of another metal, and also to appreciate the difference of conductivity of two alloys made of the same metals and only differing by a few per cent. in the relative proportions of the metals composing them. They found also that the conducting power of metals was different when they were rolled out into bars or cast, and that it was modified by molecular arrangement or position of the axes of crystallization, as was shown by the different conducting power of metals cast horizontally and vertically. Some curious results were observed in regard to alloys of gold and silver Silver being the best conductor, its conductivity is rated as 1,000, and that of gold, the next, is 981; but gold alloyed with 1 per cent. of silver has a relative conductivity of only 840.

The conduction of heat by alloys, according to Calvert and Johnson, may be considered under three general heads:

1. *Alloys which conduct heat in ratio with the relative equivalents of the metals composing them.*

2. *Alloys in which there is an excess of equivalents of the worse conducting metal over the number of equivalents of the better conductor*, such as alloys composed of 1 Cu and 2 Sn, 1 Cu and 3 Sn, &c., and which present the curious and unexpected rule that *they conduct heat as if they did not contain a particle of the better conductor*, the conducting power of such alloys being the same as if the bar was entirely composed of the worse conducting metal. A not less remarkable fact is that the alloys of a series, such as those of 2 equivalents of bismuth and 1 of lead, 3 Bi and 1 Pb, 4 Bi and 1 Pb, all conduct heat alike, the various increasing quantities of lead exercising no influence on the conductivity.

The results obtained with this class of alloys are most important to engineers; for it will be seen in the case of alloys of brass and bronze that no increase is gained in the conductivity of an alloy by increasing the quantity of a good conductor; nay, in many cases it would be a decided loss, unless a sufficient quantity of the better conducting metal be employed to bring the alloy under the third head.

3. *Alloys composed of the same metals as the last class, but in which the number of equivalents of the better conducting metal is greater than the number of equivalents of the worse conductor;* for example, alloys composed of 1 Sn 2 Cu, 1 Sn 3 Cu, &c. In this case each alloy has its own arbitrary conducting power; the conductivity of such an alloy gradually increases and tends towards the conducting power of the better conductor.

In a later experiment upon the conductivity of mercury and the amalgams, Calvert and Johnston* discovered that they had made a great mistake in their first experiment in determining the conductivity of mercury, by disregarding the fact that convection of the liquid increased the apparent conductivity. In the first experiments they found the apparent relative conductivity to be 677, silver being 1,000; but in the later experiments they determined the real relative conductivity to be only 58, or less than that of any other metal. In regard to the fluid amalgams, they found in all cases that their conductivity was nearly the same as that of pure mercury.

Weidemann,† in 1859, published a paper in which he calls in question the accuracy of the results found by Calvert and Johnson, and criticises the apparatus they used and the small size of the bars upon which they

* Phil. Trans., 1859, pp. 831–835.

† *Pogg. Annalen*, vol. 108, 1859, pp. 393–406.

ıted. He also gives the results of some experiments which he upon the conductivity of a few alloys.
ɜssen* describes a simple apparatus for showing the different ities of alloys. He also states that the conductivity for heat no evidence of whether an alloy is a chemical compound or a

CONDUCTIVITY FOR ELECTRICITY.

ıductivity for electricity, like the conductivity for heat, is one ɔperties which in some alloys is the mean of that of the compo- als, and in others seems to have no relation whatever to such

ıave been a large number of experiments made upon the electric ity of the alloys, but in this, as in the examination of other s, with widely varying results. In the first place, the determi- f the conducting powers of the metals themselves are far from as, for instance, the conductivity of copper, according to dif- perimenters, is given at numbers ranging from 66 to 100, pure ng 100.
Matthiessen† has shown that small traces of the metals, and of the metalloids, reduce the conductivity of copper to a great He states, also, that there is no alloy of copper which conducts better than pure copper, and that the fact of the wires exper- ıpon being annealed or hard drawn causes a marked difference ues obtained, annealed wire being a better conductor than hard nd, further, that temperature has likewise a marked influence, s losing in conducting power as the temperature increases.
, Professor Forbes‡ published the statement that the order of ıg powers of the metals for heat and for electricity is the same. , as a general conclusion, "that the arrangement of metallic rs of heat does not differ more from that of those of electricity er arrangement does alone under the hands of different observ-

years later, Weidemann and Franz§ arrived at the same con- regard to brass and German silver, and Weidemann‖ in 1859 l the same in regard to alloys in general. Weidemann and narked that whatever the quality may be upon which calorific ɔn depends, the close agreement of the figures renders it exceed- bable that the same quality influences in a similar manner the ɜion of electricity; for the divergence of the numbers express- ɔnductivity for heat from those expressing the conductivity for are not greater than the divergences of the latter alone, ex- y the results of different observers.
ɜst extensive series of investigations upon the electric conduc- ılloys has been made by Matthiessen. His results are published lowing papers: "On the Electric Conducting Power of the Met- On the Electric Conducting Power of Alloys";** "On the of Temperature on the Electric Conducting Power of Alloys";†† Thermo-Electric Series";‡‡ "On the Effect of the Presence of the

* Jour. Chem. Soc., vol. 5, 1867, p. 213.
† Phil. Trans., 1860, pp. 85–92.
‡ Phil. Mag. vol. 4, 1834, p. 27.
§ *Pogg. Annalen*, vol. 89, 1853, pp. 497–531.
‖ *Pogg. Annalen*, vol. 108, 1859, pp. 393–407.
¶ Phil. Trans., 1858, pp. 383–387.
** Phil. Trans., 1860, pp. 161–176.
†† Phil. Trans., 1864, pp. 167–200.
‡‡ Phil. Trans., 1858, pp, 369–381.

Metals and Metalloids upon the Electric Conducting Power of Pure Copper";* "On the Chemical Nature of Alloys".†

It was chiefly from these researches that Matthiessen arrived at the conclusions in regard to the question whether alloys are chemical compounds or mixtures, which have already been given under the head of the chemical nature of alloys.

In regard to the conducting power for electricity of the alloys, Matthiessen divides the metals into two classes:

Class A.—Those metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes.

Class B.—Those metals which, when alloyed with one of the metals belonging to class A, or with one another, do *not* conduct electricity in the ratio of their relative volumes, but always in a lower degree than the mean of their volumes.

To Class A belong lead, tin, zinc, and cadmium. To class B belong bismuth, mercury, antimony, platinum, palladium, iron, aluminum, gold, copper, silver, and in all probability most of the other metals.

CRYSTALLIZATION.

The crystallization of alloys exhibits some curious phenomena. It was formerly supposed that if a distinct crystal of an alloy were found, it would have a definite chemical composition, and would show that the alloy was not a mixture, but a veritable chemical compound.

In 1854, however, Prof. J. P. Cooke‡ published a paper on two crystalline compounds of zinc and antimony, which exhibited such properties as justified him in considering them definite chemical compounds. To distinguish them, he gave them the names of Stibiotrizincyle, with the formula $Sb\ Zn_3$, and Stibiobizincyle, with the formula $Sb\ Zn_2$. In the paper named, the crystalline form and other properties are fully described.

A short time afterward, it was found that well-defined crystals, like those described as $Sb\ Zn_3$, were obtained from the alloys containing between 43 and 60 per cent. of zinc; and even in alloys of a higher zinc percentage crystals of the same form were still seen, although they were no longer well defined. In the alloys containing between 20 and 33 per cent. of zinc, well-defined crystals, like those described as $Sb\ Zn_2$, were formed; and finally, there separated from the alloys containing between 33 and 42 per cent. of zinc, thin metallic plates, which evidently belonged to the same crystalline form.§

The same fact has been observed by Matthiessen and Von Bose‖ in regard to the alloys of gold and tin, namely, that well-defined crystals are not limited to one definite proportion of the constituents of an alloy, but are common to all gold-tin alloys containing from 43 to 27.4 per cent. of gold. They also found in the case of these alloys that the crystals and the mother liquor were never of the same composition, the percentage of gold in the mother liquor being much below that in the crystals.

From experiments by F. H. Storer,¶ it appears that the alloys of copper and zinc yield crystals, sometimes exhibiting distinct octahedral faces, sometimes in confused aggregates of crystals, but all of octahedral character, and bearing a striking resemblance to the crystals of pure

* Phil. Trans., 1860, pp. 85–92.
† British Assoc. Reports, 1863, pp. 37–48.
‡ Am. Jour. Art & Sci., vol. 18, 1854, pp. 229–237.
§ Am. Jour. Art & Sci., vol. 20, 1855, pp. 222–238.
‖ Proc. Roy. Soc., 1860–'62, pp. 433–436.
¶ Memoirs of the American Academy, vol. 8, 1863, pp. 27–56.

copper obtained by fusion. None of the crystals were found to contain a larger proportion of either metal than the remainder of the molten liquid from which they had separated. Storer concludes that all the alloys of copper and zinc crystallize in the regular system, and that they are not definite atomic compounds, but merely isomorphous mixtures of the two metals.

Calvert and Johnson* have also noticed the crystallization of the alloys of copper and zinc, and state that it is probable that Cu_2Zn and Cu_3Zn are definite compounds, as they are perfectly crystallized, and have also a special heat-conducting power of their own. They state that the most splendid of all the brass alloys is the alloy Cu Zn which is of a beautiful gold color, and crystallizes in prisms often 3 centimeters long.

Slow cooling of an alloy is apt to favor the separate crystallization of one or more of its components, and thus render it brittle. Sometimes in casting an alloy in large masses, there will be a partial separation of the constituents, and crystals of different composition will be found at the top and bottom of the mass, those at the bottom usually containing the larger percentage of the metal which has the greater specific gravity. This phenomenon has already been noted under the head of liquation.

OXIDATION AND ACTION OF ACIDS.

But few experiments have been made to determine the rate of oxidation or corrosion of the alloys by atmospheric influences or by the action of acids. It is generally found that the action of the atmosphere is less on alloys than on their component metals. An instance of this is the ancient bronze statues and coins, some of the latter of which have their characters still legible, although they have been exposed to the effects of air and moisture for upward of twenty centuries.

The action of the atmosphere on an alloy heated to a high temperature is sometimes quite energetic, as is shown in the alloy of three parts lead and one of tin, which, when heated to redness, burns briskly to a red oxide. When two metals, as copper and tin, are combined, which oxidize at different temperatures, they may be separated by continued fusion with exposure to the air. Cupellation of the precious metals is a like phenomenon.

Mushet† found that unrefined copper resisted the action of muriatic acid better than pure copper. This he thought was due to the presence of tin in the unrefined copper, as he found that an alloy of copper containing about 3 per cent. of tin resisted the action of acid to still greater extent. The latter he recommends for the purpose of ship-sheathing.

Calvert and Johnson‡ have made several experiments to determine the action of nitric, hydrochloric, and sulphuric acids upon alloys of copper and zinc and copper and tin. Some of the results they obtained were entirely unexpected. Nitric acid of 1.14 specific gravity was found to dissolve the two metals in an alloy of zinc and copper in the exact proportion in which they exist in the alloy employed, while an acid of 1.08 specific gravity dissolved nearly the whole of the zinc and only a small quantity of the copper. Hydrochloric acid of 1.05 specific gravity was found to be completely inactive on all alloys of copper and zinc containing an excess of copper, and especially on the alloy containing equivalent proportions of each metal. Zinc was found to have an extraordinary preventive influence on the action of strong sulphuric acid on copper.

* Phil. Trans., 1858, p. 367.
† Phil. Mag., vol. 6, 1835, pp. 444–447.
‡ Phil. Mag., vol. 10, 1855, pp. 250, 251; also, Jour. Chem. Soc., vol. 19, 1866, pp. 434–454.

The alloys of copper and tin were all found to resist the action of nitric acid more than pure copper, but the preventive influence of tin presents the peculiarity that the action of the acid increases as the proportion of tin increases; thus the alloy Cu Sn_5 is attacked ten times more than the alloy Cu Sn. The alloys Sn Cu_2 and Sn Cu_3 were attacked by strong sulphuric acid with more violence than any other of the bronzes.

Three alloys, viz, Cu_{18}, Zn Sn, Cu_{10} Zn Sn, and Cu_4 Zn_3, were found to be only slightly attacked by strong nitric or hydrochloric acids, and not at all by sulphuric acid. The resistance to the action of nitric acid is remarkable, as its action on each of the component metals is very violent.

A. Bauer* has recently published in the *Berichte der deutschen chemischen Gesellschaft* the result of some experiments on the action of hot sulphuric acid on several alloys of lead. These experiments show that the addition of a little antimony or copper renders the alloy more able to resist sulphuric acid, while bismuth has a decidedly injurious effect.

HARDNESS AND OTHER MECHANICAL PROPERTIES.

The mechanical properties of the alloys, such as hardness, malleability, ductility, resistance to strains of tension, compression, and torsion, elasticity, resilience, &c., are of the utmost importance to the engineer, but, at the same time, it is most difficult to find reliable information regarding them. But few experimenters of authority have investigated the subject, and their researches, although valuable as far as they go, are too limited in extent to allow of a complete classification and comparison. A few alloys which are of special service in the arts have been well studied by those who have had occasion to use them, with a view to learn their mechanical properties, not as a matter of scientific interest, but as an actual necessity. This has been the case especially with the various gun-metals, upon which many experiments have been made under authority of the different governments, so that among all the alloys our knowledge of the gun-metals is the most extensive and accurate. In like manner the properties of journal and anti-friction metals have been investigated by those who are concerned in their manufacture and use.

With these, and a few other exceptions, however, our information on the mechanical properties of the alloys is very meager. It will be the endeavor of the Committee, as far as possible, to supply this manifest want by a series of experiments on a large number of alloys, testing them for all the mechanical properties above named.

The hardness of some of the alloys has been investigated by Calvert and Johnson.† They used an apparatus for determining the hardness, which consists, chiefly, of a conical steel point of a certain size, which is pushed into the material whose hardness is to be determined a given distance by means of weights applied at the end of a lever. The relative hardness is shown by the weight required for the different materials.

A somewhat similar apparatus was used by Major Wade‡ in determining the hardness of gun-metal, but he used a diamond-shaped point and a fixed weight, determining the relative hardness by the distance which the point was pushed into the metal. General Uchatius,§ in experiments for the Austrian Government, used an indenting tool, which was forced into the metal to be tested by a weight of 4.4 pounds falling

* Scientific American, vol. 33, 1875, p. 135.
† Phil. Mag., vol. 17, 1859, pp. 114–121.
‡ Report of Experiments on Metals for Cannon, Phila., 1856.
§ Ordnance Notes No. XL, Washington, D. C., 1875.

through a height of 9¾ inches. The shorter the cut made by the indenting tool, the greater was the hardness.

Mallet,* in 1842, in his experiments on the alloys of copper and tin and copper and zinc determined their tensile strength, and also the order of their ductility, malleability, and hardness. In his work on the Construction of Artillery,† published in 1856, the same author discusses the physical and mechanical properties of gun-metal, showing the effects of sudden and of rapid cooling, and the deteriorating effect of small proportions of a third metal, such as iron, zinc, lead, or antimony.

In regard to the extent of our knowledge upon these subjects, he remarks: "Gun-metal, probably the very earliest used material for cannon, is that which has received the least improvement or systematization of our knowledge as to its use, up to the present time; the archæologist finds the rude weapons of Scandinavian, Celtic, Egyptian, Greek, and Roman warfare formed of nearly the same alloys of copper and tin, and in about the same proportions as the cannon of to-day."

The circumstances of chief difficulty and importance in the manipulation of gun-metal, as affecting the production of cannon, are:

1st. The chemical constitution of the alloy, as influencing the balance of its hardness, rigidity, or ductility, and tenacity.

2d. Its chemical constitution, and what other conditions, influence the segregation of the cooling mass of the gun when cast into two or more alloys of different and often variable composition.

3d. The effects of rapid and of slow cooling, and of the temperature at which the metal is fused and poured.

4th. The effects due to repeated fusions, and to foreign constituents, in minute proportions entering into the alloy.

The circumstances of manipulation, as above named, have already been shown to have a vast influence upon nearly all the properties of the alloys, and their study is of the greatest importance, not only in reference to gun-metals, but to all alloys which may be used as materials of construction.

In connection with the subject of gun-metal, the experiments lately made by General Uchatius‡ for the Austrian Government are of interest. He found that the tenacity, elasticity, and hardness of bronze were increased to an extraordinary degree by driving a series of conical steel mandrels or plugs, gradually increasing in size, into the bore of the gun. The metal in the interior of the gun was thus stretched or strained much beyond its elastic limit, and was thereby given a new molecular condition, which enables it better to resist both the expansive force of the exploded powder, and the abrading effects of the shot.

The results of the experiments of General Uchatius have been communicated to the Ordnance Department of the United States by Col. T. T. S. Laidley, U. S. A., who calls attention to the fact that experiments were made upon bronze, with a view to improve its quality for guns, by Mr. S. B. Dean, of Boston, in 1868–'69, at which time he used the identical mode of improving the bronze adopted by General Uchatius some four years later. Patents for the improvement were secured in May, 1869, not only in this country, but also in England, France, and Austria. The want of funds rendered it necessary for Mr. Dean's experiments to be discontinued.

Bischof§ describes an apparatus for determining the qualities of the

* Phil. Mag., vol. 21, 1842, pp. 66–68.
† Mallet, Construction of Artillery, London, 1856, pp. 80–101.
‡ Ordnance Notes No. XL, Washington, D. C., 1875.
§ British Assoc. Reports, 1870, pp. 209, 210.

malleable metals and alloys, which is based upon the principle that "superior qualities of malleable metals and alloys are characterized by their being able permanently to extend in all directions by rolling or hammering without rupture, while inferior qualities break before reaching the maximum of extension which the former can endure." His apparatus is used to bend the metal or alloy to be tested, which is of a certain size and shape, in contrary directions through a certain angle. The oftener the piece can be so bent without breaking the better is its quality.

LIST OF AUTHORITIES.

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Describes experiments made upon several compounds of copper and phosphorus. Copper with 0.75 per cent. of phosphorus was found to have a tensile strength of 45,000 pounds per square inch.

ABEL. *Legirungen von Gold, Silber, und Kupfer mit Cadmium für Juwelierarbeiten.* Alloys of gold, silver, and copper, with cadmium for jewelry. Dingler's *Journal*, vol. 167, 1863, pp. 288, 289.

ABEL and FIELD. Some Results of the Analyses of Commercial Coppers. By F. A. Abel, F. R. S., and Frederick Field, F. R. S. E. Jour. Chem. Soc., vol. 14, 1862, pp. 290–303.

Contains a complete table of the analyses of a large number of commercial coppers, with descriptions of the methods of analyses.

ALLEN. On the Alloys of Copper, Tin, Zinc, Lead, and other Metals with Manganese. By J. Fenwick Allen, F. C. S. British Assoc. Reports, 2, 1870, p. 50.

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ANDERSON. Anderson's Strength of Materials and Structures. 1 vol., London, 1872.

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BABBITT. Babbitt Metal. Scientific American, vol. 12, 1856, p. 326. U. S. Patents, July 17, 1839.

A patent was issued to Isaac Babbitt July 17, 1839, for the construction of boxes for the journals, wheels, and axles of carriages, but it does not embrace a peculiar metal, as is generally supposed. It simply covers the lining of a hard shell of metal with a softer metal for the bearings of axles.

BABINET. *Rapport sur deux Mémoires de Wertheim intitulés Recherches sur l'élasticité.* Report on two memoirs of M. Wertheim entitled, Researches on Elasticitity. *Comptes Rendus*, vol. 18, 1844, pp. 921–932.

(See Wertheim.)

BARRUEL. *Sur un nouvel alliage d'argent remarquable par sa dureté.* On a new alloy of silver remarkable for its hardness. By Germain Barruel. *Comptes Rendus*, vol. 35, 1852, p. 759.

BAUER. Action of Sulphuric Acid on Lead and its Alloys. By A. Bauer. Published recently in the *Berichte der deutschen chemischen Gesellschaft.* Scientific American, vol. 33, p. 135, August 28, 1875.

BERTHIER. *Legirungen von Zinc und Eisen.* Alloys of zinc and iron. Liebig's *Annalen*, vol. 40, 1841, pp. 186–189.

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Applicable to the casting of type and other metals. Contains 100 parts lead, 30 antimony, 20 tin, 8 nickel, 5 cobalt, 8 copper, 2 bismuth.

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Describes an apparatus termed a "Metallometer," used for determining the quality of the malleable metals and alloys by bending them in contrary directions.

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Account of the beginning of a series of experiments on the alloys. Alloys of the following metals are described: Iron and potassium, iron and aluminum, iron and zinc, zinc, tin, and copper. This paper also describes the action of acids on some of the alloys.

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Marked differences between results and those of other experimenters. In all the alloys examined the expansion was far less than that deduced from their equivalents.

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— On phosphoric bronze. *Comptes Rendus*, vol. 73, 1871, pp. 68–1470.

MM. H. de Ruolz and A. de Fontenay presented a communication to the French Academy of Sciences, in which, after referring to a paper by Levi and Künzel (see Levi and K., Essais, &c.), they claim that they used the identical processes described by these authors in experiments made for the French Government from 1854 to 1859, but that they had kept them secret up to this time (1871). They claim that they were the first to use phosphorus in bronze for artillery, and also manganese for the same purpose, whether alone or associated with other metals.

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——— *Recherches sur les métaux, et en particulier sur l'aluminium et sur une nouvelle forme de silicium.* Researches on the metals, and in particular on aluminum and on a new form of silicon. *Ann de Chim.*, vol. 43, 1835, pp. 5–36.

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DUNLEVIE. *Lagermetall.* Metal for journal bearings. Dingler's *Journal*, vol. 177, 1865, pp. 326, 327. London Journal of Arts, 1865, p. 205.

Alloy containing tin, zinc, copper, and antimony, heats very little by friction.

DUSSAUSSOY. *Résultat des expériences faites par ordre de Son Excellence le Mareschal Duc de Feltre, ministre de la Guerre, sur les alliages de cuivre, d'étain, de zinc et de fer, considérés sous le rapport de la fabrication des bouches à feu, et autres objets semblables.* Result of experiments made, &c., on the alloys of copper, tin, zinc, and iron, considered with reference to the manufacture of cannon and other like objects. By M. Dussaussoy. *Ann. de Chim.*, vol. 5, 1817, pp. 113–121; 225–234.

ECLECTIC. Van Nostrand's Eclectic Engineering Magazine. 1869, p. 172. Alloys fusible at specified temperatures. 1873, vol. 8, p. 570. White metal for machinery.

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ENGINEER. Phosphorized Bronze and other Alloys as a Material for Artillery. Engineer, London, vol. 33, 1872, pp. 127, 128, 145, 146, 179, 181.

A valuable article, giving results of experiments.

FARADAY. *Lettre au Prof. De la Rive sur les alliages que forme l'acier avec differents métaux.* Letter to Prof. De la Rive on the alloys which steel forms with different metals. *Bibliothèque Universelle*, vol. 14, 1820, pp. 209–215. (See Stodart and Faraday.)

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FREMY. *Note sur le chrome cristallizé et sur les alliages d'aluminium.* Note on crystallized chromium and on aluminum alloys. *Comptes Rendus*, vol. 44, 1857, p. 632.

GEDGE. Improvements in the manufacture of metallic compounds. British patent, 1853, Nov. 12, No. 2626.

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GENTH. Analysis of Chinese Alloys. By F. A. Genth. Jour. Frank. Inst., vol. 36, 1858, p. 261. Phil. Mag., vol. 16, 1858, pp. 420–426.

Some Chinese coins were found to contain chiefly copper and zinc, with small traces of other metals. As many as eight metals were found in one alloy.

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GRAHAM. The Brassfounder's Manual. By Walter Graham. 1 vol., London, 1870.

Instructions for modeling, pattern-making, molding, alloying, turning, filing, bronzing, &c.

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IRON AGE. Mar. 27, 1873, p. 1. Melting Points of Lead and Tin Alloys. Dec. 10, 1874. The deposition of alloys.

JACOBY. Improvement in metallic alloy. By J. E. Jacoby. British patent, October 7, 1873, No. 3246. Chemical News, vol. 30, 1874, p. 10.

Alloys containing from 70 to 73 per cent. of copper, 9 to 11 per cent. tin, 15 to 20 per cent. lead, and from 0.05 to 1 per cent. zinc for journal bearings and like purposes.

JACOBI. *Vorzügliche Legirung für Zapfenlager.* Excellent alloy for journal boxes. By R. Jacobi. Dingler's *Journal*, vol. 167, 1863, p. 463.

Alloy of 5 parts copper, 85 tin, and 10 antimony.

JAHRESBERICHT. *Jahresbericht ueber die Leistungen der chemischen Technologie*, von Rudolf Wagner, Leipzig.

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JOHNSON. Alloy of Wrought and Cast Iron to Replace Steel. Practical Mechanics' Journal, 2d series, vol. 5, p. 207.

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Describes amalgams of iron, copper, silver, platinum, zinc, lead, and tin.

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Vol. 2, pp. 94–97. Under the head of *Metalllegirungen* is found a list of one hundred papers by various authorities, having more or less reference to the alloys.

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——— *Dichtigkeit des Cadmium Amalgams.* Density of cadmium amalgams. Liebig's *Annalen*, vol. 40, 1841, p. 186.

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P. Copper and Zinc Alloy. By M. E. Kopp. Chemical News, vol. 1861, p. 91.

Alloy of 60 parts copper, 38.15 zinc, 1.50 iron, remarkable for its malleability.

ZEL. (See Levi and Künzel.)

FFER. *Note sur la pesanteur spécifique des alliages et leur point de sion.* Note on the specific gravities of the alloys and their points fusion. Ann. de Chim., vol. 40, 1829, pp. 285–303. Quart. Jour. i., vol. 2, 1829, pp. 185, 186.

Describes experiments on the specific gravities and points of fusion of the alloys and amalgams of tin and lead.

OND. *Ueber die Bronzen und andere Legirungen.* On bronzes and her alloys. Dingler's *Journal*, vol. 135, 1855, pp. 269–276.

A list of a number of alloys, chiefly of copper, tin, lead, and antimony, with a description of their properties and uses.

KIN. The Brass and Iron Founders' Guide. By James Larkin. 1 l., Phila., 1874.

A concise treatise on brass founding and molding; the metals and their alloys, &c.

GIER. *Analyse de quelques alliages de bismuth.* Analysis of some loys of bismuth. Ann. de Chim., vol. 36, 1827, pp. 332–334. Ding- r's *Journal*, vol. 27, 1828, p. 240.

I and KÜNZEL. *Essais sur l'emploi de divers alliages, et spécialement u bronze phosphoreux, pour la coulée des bouches à feu.* Experiments the use of various alloys, and especially of phosphoric bronze, for e casting of cannon. By MM. Montefiore Levi and C. M. Künzel. *omptes Rendus*, vol. 73, 1871, pp. 530–534.

— The same, translated into English by John D. Brandt, chief clerk ureau of Ordnance, Navy Department, United States. 1 vol., Wash- gton, Government Printing Office, 1872.

Contains complete tables of a valuable series of experiments on metals for cannon. Bronzes containing manganese, nickel, iron, zinc, and phosphorus were experimented upon.

— Bronze Alloy. United States patents granted to G. M. Levi and M. Künzel, May 23, 1871, No. 115220, and Nov. 14, 1871, No. 120984.

I. On Phosphoric Bronze and its Principal Industrial Uses. By C. Montefiore Levi. Amer. Chemist, vol. 5, 1874, pp. 178–180. ingler's *Journal*, vol. 211, 1874, p. 322.

OL. *Memoires sur le dosage de l'arsenic dans les métaux usuels et dans r alliages.* Memoirs on the amount of arsenic in the usual metals d their alloys. *Ann. de Chim.*, vol. 16, 1846, pp. 493–504.

— *Note sur une nouvelle cause d'hétérogénéité des alliages d'argent et cuivre produit par absorption d'oxigène.* Note on a new cause of terogeneity of the alloys of silver and copper, produced by the sorption of oxygen. *Revue Sc entifique*, vol. 10, 1846, pp. 211–213.

— *Memoire sur les alliages métalliques considérés sous le rapport de r composition chimique.* Memoir on the alloys considered with ref- ence to their chemical composition. *Ann. de Chim.*, vol. 36, 1852, . 193–224; vol. 39, 1853, pp. 163–184. *Journ. de Pharm.*, vol. 17, 50, pp. 111–114. Erdmann's *Journal*, vol. 60, 1853, pp. 449–456.

— *De l'influence du bismuth sur la ductilité de cuivre.* On the influ- ce of bismuth on the ductility of copper. Paris, *Bull. de la Soc. courr.*, vol. 4, 1853, pp. 746–748.

LEVOL. *Legirung von Gold und Silber.* Kupfer; Silber mit Blei. Alloys of gold and silver, gold and copper, silver and lead. Dingler's *Journal*, vol. 136, 1855, pp. 453–454. *Ann. de Chim.*, vol. 39, p. 163.

——— *Legirung von Silber mit Kupfer.* Alloys of silver and copper. Dingler's *Journal*, vol. 130, 1853, pp. 128–129.

LIPOWITZ. *Ueber Wood's leichtflüssiges Metall.* On Wood's easily-fusible metal. Dingler's *Journal*, vol. 158, 1860, pp. 376, 377.

Describes several fusible alloys which melt at points between 60° and 95° C.

MALLET. Chemical and Physical Properties of the Atomic Alloys of Copper and Zinc, and Copper and Tin. By Robert Mallet, F. R. S. Phil. Mag., vol. 21, 1842, pp. 66–68. Dingler's *Journal*, vol. 85, 1842, p. 378.

Tables giving the chemical composition, specific gravity, color, fracture, cohesion, and order of ductility, malleability, hardness, and fusibility of the alloys of copper and zinc and copper and tin.

——— On a Metallic Alloy in an Unusual State of Aggregation. Phil. Mag., vol. 23, 1848, p. 141.

A new alloy was formed by portions of abraded brass in a journal-bearing being forced into close contact. It was of identical composition with the original brass, but was black in color, and had only one-fifteenth of its strength.

——— On the Physical Conditions involved in the Construction of Artillery. 1 vol., London, 1856.

Contains a discussion of the properties of bronze as a material for cannon, with the effects of rapid and of slow cooling, and the effects due to repeated fusion and to the presence of impurities in minute proportions.

MATTHIESSEN. On the Specific Gravities of Alloys. By A. Matthiessen, F. R. S. Phil. Trans., 1860, pp. 177–184. Proc. Roy. Soc., vol. 10, 1859–'60, pp. 12, 13. Pogg. *Annalen*, vol. 110, 1860, pp. 21–37.

An extensive research upon the specific gravities of 18 different series of alloys.

——— On an Alloy which may be used as a Standard of Electrical Resistance. Phil. Mag., vol. 21, 1861, pp. 107–115.

Recommending the alloy of 2 parts gold and 1 part silver as a standard of electrical resistance.

——— Note on Professor Bolley's communication "On some Physical Properties of the Alloys of Tin and Lead." *Jour. Chem. Soc.*, vol. 15, 1862, pp. 105–107.

Criticism of Professor Bolley's method of finding the calculated specific gravities.

——— On the Electric Conducting Power of Alloys. Phil. Trans., 1860, pp. 161–176. Proc. Roy. Soc., vol. 10, 1859–'60, pp. 205–206. Pogg. *Annalen*, vol. 110, 1860, pp. 190–221.

A valuable research on the electric conducting power of 18 different series of alloys.

——— Report on the Chemical Nature of Alloys. British Assoc. Reports, 1, 1863, pp. 37–48.

Complete classification of the alloys according to their chemical nature, as deduced chiefly from experiments upon their conductivity.

——— On the Variation of the Electrical Resistance of Alloys due to a change of Temperature. British Assoc. Reports, 2, 1863, pp. 124–127. Electrician, vol. 4, 1863, pp. 285, 286, 296.

——— On the Electrical Permanence of Metals and Alloys. British Assoc. Reports, 1863, 2, pp. 127–130. Electrician, vol. 4, 1863, pp. 296, 297, vol. 5, p. 5.

MATTHIESSEN. On Alloys. Jour. Chem. Soc., vol. 5, 1867, pp. 201–220.

A discourse on the general nature and properties of alloys, and reasons deduced from experiment for the author's adoption of certain views on the subject.

MATTHIESSEN and VON BOSE. On the Lead-Zinc and Bismuth-Zinc Alloys. By A. Matthiessen, F. R. S., and M. Von Bose. Proc. Roy. Soc., vol. 11, 1860–'62, pp. 430–433. Erdmann's *Journal*, vol. 84, 1861, pp. 323–326.

Lead and zinc do not alloy in all proportions. The results show that lead will dissolve only 1.6 per cent. of zinc and zinc only 1.2 per cent. lead; that zinc will dissolve only 2.4 per cent. of bismuth and bismuth from 8.6 to 14.3 per cent. zinc.

——— On some Gold-Tin Alloys. Proc. Roy. Soc., vol. 11, 1860–'62, pp. 433–436. Erdmann's *Journal*, vol. 84, 1861, pp. 319–322.

Describing some experiments on the crystallization of some of the alloys of gold and tin.

MATTHIESSEN and VOGT. On the Influence of Temperature on the Electric Conducting Power of Alloys. By A. Matthiessen, F. R. S., and Carl Vogt. Phil. Trans., 1864, pp. 167–200.

A research on the electric conducting power of a large number of alloys at different temperatures.

MATTHIESSEN and HOLZMANN. On the Effect of the Presence of the Metals and Metalloids on the Electric Conductivity of Pure Copper. By A. Matthiessen, F. R. S., and M. Holzmann. Phil. Trans., 1860, pp. 85–92. Pogg. *Annalen*, vol. 110, 1860, pp. 222–234.

MAUMENÉ. *Note sur les bronzes du Japan.* Note on the bronzes of Japan. By E. G. Maumené. *Comptes Rendus*, vol. 80, 1875, pp. 1009, 1010. Scientific American, Oct. 30, 1875, p. 281.

MICHEL. *Ueber krystallisirte Verbindungen von Aluminium mit Metallen.* On crystallized compounds of aluminum with metals. Liebig's *Annalen*, vol. 115, 1860, pp. 102–105. Erdmann's *Journal*, vol. 82, 1861, pp. 237, 238. Phil. Mag., vol. 20, 1860, p. 377.

Describes alloys of aluminum with tungsten, molybdenum, manganese, iron, nickel, and titanium.

MILLER. On the Form of an Alloy of Bismuth. By Wm. Hallows Miller. Phil. Mag., vol. 12, 1856, pp. 48, 49.

Describes crystallization of an alloy of bismuth containing nickel, copper, and sulphur.

MORIN. *Sur quelques bronzes de la Chine et du Japan à patine foncée.* On some bronzes of China and Japan with dark patina. By M. H. Morin. *Comptes Rendus*, vol. 78, 1874, pp. 811–814.

MUNTZ. Ship-sheathing metal. British patents, 1832, Oct. 22, No. 6325. 1846, Oct. 15, No. 11410. 1852, May 8, No. 14117. 1858, Mar. 19, No. 572. 1858, May 21, No. 1134. London Journal of Arts, May, 1847, p. 268. Dingler's *Journal*, vol. 104, 1847, p. 465.

MUSHET. On the Alloys of Iron and Copper. By David Mushet. Phil. Mag., vol. 6, 1835, pp. 81–85. Dingler's *Journal*, vol. 56, 1835, p. 11.

The author claims to have established the practicability of alloying malleable iron with copper in every reasonable proportion.

——— On the Immersion of Copper for Bolts and Ship-Sheathing in Muriatic Acid as a Test of its Durability. Phil. Mag., vol. 6, 1835, pp. 444–447.

Unrefined copper was found to resist the action of muriatic acid better than pure copper. This was proved to be due to the presence of tin.

MUSHET. Alloys of Tungsten. Several patents for the same. See British patent reports. Abridgment of Specifications relating to Metals and Alloys. London, 1861.

MUSPRATT. Muspratt's Chemistry, vol. 1, pp. 533–553. Article on Copper Alloys.

A valuable article. Includes a description of the method of casting bronze guns, and the changes of density, hardness, &c., of bronze by tempering.

MUSSCHENBROEK. Musschenbroek is referred to by several writers as having made experiments upon alloys in the first part of the last century. See Encyclopædia Britannica; article, Strength. Also, Knight's Am. Mech. Dictionary.

NETKE. *Weissguss für Lager.* White casting for journals. Dingler's *Journal*, vol. 168, 1863, p. 74.

Alloy of 8 parts tin, 2 parts antimony, 1 part copper. Used by General Steam Navigation Company of London for wheel and propeller shafts, &c.

OXLAND. Improvements in Manufacture of Alloys containing Tungsten. British patent, 1857, December 18, No. 3114.

DE PARADIS. *Das Aich-Metall und das Sterro-Metall, zwei neue Metall-legirungen.* Aich-metal and sterro-metal, two new metallic alloys. Dingler's *Journal*, vol. 160, 1861, pp. 34–40.

Description of these two alloys and their mechanical properties.

PARKES. Several valuable alloys made by Mr. Parkes, described in Ure's Dictionary, vol. 1; article, Alloy. See, also, British Patents. Abridgment of Specifications relating to Metals and Alloys. London, 1861. Dingler's *Journal*, vol. 116, 1850, pp. 78–80. Mechanics' Magazine, vol. 51, p. 309.

PATENTS, U. S. General Index of Patents, 1790 to 1873, U. S. Patent Office.

Contains list of 53 patents having reference to alloys.

PATENTS, G. B. Abridgments of the Specifications relating to Metals and Alloys. Printed by order of the British Commissioner of Patents. London, 1861.

Contains abridgments of specifications of more than 100 patents of alloys, dating between 1664 and 1859.

PELIGOT. *Sur les alliages d'argent et de zinc.* On the alloys of silver and zinc. By Eugene Peligot. *Comptes Rendus*, vol. 58, 1864, pp. 645–651.

PERCY. On some of the Alloys of Tungsten. By John Percy, F. R. S. British Assoc. Reports, 2, 1848, p. 57.

Experiments on the economic use of tungsten in alloys. The results were unsatisfactory.

——— On Copper containing Phosphorus, with Details of Experiments on the Corrosive Action of Sea Water on some varieties of Copper. British Assoc. Reports, 2, 1849, pp. 39, 40.

Describes an alloy containing copper 95.72, iron 2.41, phosphorus 2.41. On its being exposed to sea water for 9 months there was no loss of weight.

——— Metallurgy. Vol. 1. Fuel; Fire Clays; Copper; Zinc; Brass, etc. London, 1861.

Contains a valuable account of brass and other alloys of copper.

——— Metallurgy. Vol. 2. Iron and Steel. London, 1864; pp. 147–197.

Contains a very full account of the alloys of iron with other metals.

PERSON. *Solution d'une problème sur la fusion des alliages.* Solution of a problem on the fusion of the alloys. By C. C. Person. *Comptes Rendus*, vol. 23, 1846, pp. 626–629. Pogg. *Annalen*, vol. 70, 1847, pp. 388–392.

Experiments on some alloys of bismuth, lead, and tin. M. Person concludes that it is possible to assign in advance the heat necessary to fuse an alloy, if that required to fuse each of its components is known.

——— *Sur la chaleur spécifique anomale de certains alliages et sur leur réchauffement spontané après la solidification.* On the anomalous specific heat of certain alloys and their spontaneous reheating after solidification. *Comptes Rendus*, vol. 25, 1847, pp. 444–446. Liebig's *Annalen*, vol. 64, 1847, pp. 179–185.

PILLICHODY. On some Physical Properties of the Alloys of Tin and Lead. By G. Pillichody. Jour. Chem. Soc., vol. 15, 1862, pp. 30–32. *Polytechnisches Centralblatt*, 1862, p. 88.

POLAIN. *Ueber die Festigkeit der Phosphorbronze und über deren Anwendungen in der Industrie.* On the strength of phosphor-bronze, and on its applications in industry. By Alphons Polain. Dingler's *Journal*, 1875, vol. 217, pp. 482–494. Extract from the *Revue Universelle*, 1874, vol. 35, p. 595.

Account of experiments made in Belgium, France, and Germany on phosphor-bronze as a material for guns, and statement of its other industrial applications.

RAMMELSBERG. *Ueber einige krystallisirte Zinnhüttenproducte von Schlackenwalde und krystallisirte Legirungen im Allgemeinen.* On some crystallized products of tin furnaces and crystallized alloys in general. Pogg. *Annalen*, vol. 120, 1863, pp. 54–65.

REGNAULT. *Sur les chaleurs spécifiques des corps composés solides et liquides.* On the specific heat of solid and liquid compound bodies. By M. Victor Regnault. *Ann. de Chim.*, vol. 1, 1841, pp. 129–207. Erdmann's *Journal*, vol. 25, 1842, pp. 129–170. *Comptes Rendus*, vol. 12, 1841, pp. 56–83.

An extensive investigation on the specific heat of compound bodies, including the metallic alloys.

RENAULT. *Nouvelle methode d'analyse quantitative applicable aux differents alliages.* New method of quantitative analysis, applicable to different alloys. By M. B. Renault. *Comptes Rendus*, vol. 60, 1865, p. 489. Dingler's *Journal*, vol. 176, 1865, pp. 371–374.

RICHE. *Recherches sur les alliages métalliques.* Researches on the metallic alloys. By M. Alf. Riche. *Comptes Rendus*, vol. 55, 1862, pp. 143–147. Dingler's *Journal*, vol. 170, 1863, pp. 113–114.

Experiments on the specific gravities, &c., of the alloys of tin and lead, lead and bismuth, antimony and lead, bismuth and tin.

——— *Recherches sur les alliages.* Researches on the alloys. *Comptes Rendus*, vol. 67, 1868, pp. 1138–1140.

A series of 15 alloys of copper and tin was examined with reference to their density, fusibility, and liquation.

——— *Recherches sur les alliages.* Researches on the alloys. *Comptes Rendus*, vol. 69, 1869, pp. 343–346.

Discussion of the effect of reheating and shock on the density of alloys of copper and tin.

——— *Note sur les bronzes des instruments sonores.* Note on the bronzes of sonorous instruments. *Comptes Rendus*, vol. 69, 1869, pp. 985, 986.

Mentions the ineffectual attempts made in France to imitate the cymbals and tam-tams of the Chinese.

RICHE. *Recherches sur les alliages.* Researches on the alloys. *Ann. de Chim.*, vol. 30, 1873, pp. 351–419. Dingler's *Journal*, 1874, vol. 213, pp. 150–159, 342–353, 514–523, 540; vol. 214, pp. 153–163, 243–248, 305–312.

An extensive and valuable research upon the alloys, especially those of copper and tin, with regard to their fusibility, liquation, and the modifications which they undergo under the influence of tempering, annealing, and mechanical operations.

RICHE and CHAMPION. *Fabrication des tam-tams et des cymbales.* Manufacture of tam-tams and cymbals. By MM. Alf. Riche and P. Champion. *Comptes Rendus*, vol. 70, 1870, pp. 85–88.

Describes the process of manufacture employed by the Chinese as seen by M. Champion at Shanghai.

ROBERTS. The Molecular Arrangement of the Alloy of Silver and Copper Employed for the British Silver Coinage. By W. C. Roberts, chemist to the mint. Brit. Assoc. Reports, 1871, p. 80.

The strips used for the coins contained more silver in the center than in the external edges by two parts in 1,000.

——— On the Liquation, Fusibility, and Density of Certain Alloys of Silver and Copper. Proc. Roy. Soc., vol. 23, 1875, pp. 481–495.

Contains an account of a valuable set of experiments on the melting-points of a series of alloys of silver and copper, on their liquation when rapidly or slowly cooled, and on their density when fluid.

RIEFFEL. *Memoire sur les combinaisons chimiques du cuivre avec l'étain.* Memoir on the chemical combinations of copper with tin. *Comptes Rendus*, vol. 37, 1853, pp. 450–453. Erdmann's *Journal*, vol. 60, 1853, pp. 370–374.

RUDBERG. *Ueber eine allgemeine Eigenschaft der Metalllegirungen.* On a general property of the metallic alloys. Pogg. *Annalen*, vol. 18, 1830, pp. 240–249.

——— *Ueber die Wärmemengen in Metallgemischen.* On the quantities of heat in metallic compounds. Pogg. *Annalen*, vol. 71, 1847, pp. 460–463. Liebig's *Annalen*, vol. 64, 1847, pp. 183, 184.

SEMRAD and STERBENZ. Applications of Phosphor-Bronze. By G. Semrad and J. Sterbenz. *Deutsche Industriezeit.*, 1874, p. 323. Wagner's *Jahresbericht*, 1874, pp. 149, 150.

SCHUBARTH. Schubarth's *Repertorium der technischen Literatur.* A list of scientific papers published between the years 1823 and 1853. Contains, under the head of *Metalllegirungen*, a list of more than a hundred papers having reference to the alloys.

SHARMAN. White Metal. Scientific American, vol. 14, 1858, p. 25. Improved metallic compound, applicable to the manufacture of various useful and ornamental articles. British patent, 1857, October 13, No. 2621.

Tin, 16; lead, 3 or 4; zinc, 5. Said to be cheaper than most white metal.

SMITH. On the Liquation of Alloys of Silver and Copper. By Col. J. T. Smith, Madras Engineers, F. R. S. Proc. Roy. Soc., vol. 23, 1875, pp. 433–435.

Observations made at the Indian mints on the causes which influence the liquation of the coin alloys of silver and copper.

STODART and FARADAY. Experiments on the Alloys of Steel, made with a view to its Improvement. By J. Stodart, F. R. S., and M. Faraday. Quart. Jour. Sci., vol. 9, 1820, pp. 319–330. *Ann. de Chim.*, vol. 16, 1820, pp. 127–144.

——— On the Alloys of Steel. Phil. Trans., 1822, pp. 253–270. *Ann. de Chim.*, vol. 21, 1822, pp. 62–74. Dingler's *Journal*, vol. 8, 1822, p. 252.

STOVER. On the Alloys of Copper and Zinc. By Frank H. Stover. Chemical News, vol. 2, 1860, pp. 303–305; vol. 3, 1861, pp. 22–24, 37–38, 51–53, 70–72, 149–151, 164–166. Memoirs of the American Academy, vol. 8, 1863, pp. 27–56. Erdmann's *Journal*, vol. 72, 1861, pp. 239–242.

Experiments on the crystallization of the alloys of copper and zinc. Stover concludes that all the alloys of copper and zinc are simply isomorphous mixtures of the two metals.

THOMSON. Analysis of a Chinese Gong. By Thomas Thomson. Thomson's Ann. Phil., vol. 2, 1813, pp. 208–210. *Ann. de Chim.*, vol. 87, 1814, pp. 46–53.

Copper, 80.427; tin, 19.573. Remarkable for its high specific gravity—8.953.

——— On the Melting Points of Alloys of Lead, Tin, Bismuth, and Zinc. Glasgow Phil. Soc. Proc., vol. 1, 1841–'44, pp. 77–82.

TISSIER. *Note sur les alliages d'aluminium.* Note on the alloys of aluminum. By Chas. and Alex. Tissier. *Comptes Rendus*, vol. 43, 1856, pp. 885, 886. Erdmann's *Journal*, vol. 69, 1856, p. 381. Dingler's *Journal*, vol. 143, 1857, pp. 42–45.

——— *Ueber Metalllegirungen mit besonderer Berücksichtigung des Aluminiums.* On metallic alloys, with special reference to those of aluminum. Dingler's *Journal*, vol. 166, 1862, p. 427. From the *Technologiste*, April, 1862, p. 348.

TOUCAS. *Silberaehnliche Legirung.* Alloy resembling silver. Dingler's *Journal*, vol. 143, 1857, p. 157. British patent, 1856, February 22, No. 459.

Alloy of 4 parts copper, 5 tin, 1 each lead, zinc, and antimony.

TROOST and HAUTEFEUILLE. *Sur les alliages de l'Hydrogène avec les Métaux.* On the alloys of hydrogen with the metals. By MM. L. Troost and P. Hautefeuille. *Ann. de Chim.*, vol 2, 1874, pp. 273–288. *Comptes Rendus*, vol. 78, 1874, pp. 807–811.

Describes alloys of hydrogen with sodium, potassium, and palladium.

URE. Ure's Dictionary of Arts, Mines, and Manufactures. Vol. 1, articles on alloys, brass, bronze, &c.

UCHATIUS. Report of experiments made by General Uchatius for the Austrian Government on hardening bronze for cannon. Translated into English, and communicated to the Ordnance Department of the United States, by Col. T. T. S. Laidley, U. S. A. Published as "Ordnance Notes No. XL, Washington, D. C., 1875."

Extraordinary hardening and increase of strength of bronze guns were produced by driving mandrels or plugs into the bore. Some specimens of hardened bronze had a tensile strength of 70,000 pounds per square inch.

VOGEL. *Legirung zu Compositions feilen.* Alloy for composition files. Dingler's *Journal*, vol. 159, 1861, pp. 211, 212.

——— A new Alloy of Copper and Aluminum for Journal Brasses. Scientific American, vol. 4, 1861, p. 311.

VON HAUER. *Ueber die leicht schmelzbaren Kadmium-Legirungen.* On the easily fusible cadmium alloys. By Carl Ritter von Hauer. Dingler's *Journal*, vol. 176, 1865, p. 371. Erdmann's *Journal*, vol. 94, 1865, pp. 436–439. Phil. Mag., vol. 30, 1865, pp. 447–448.

VIGOUROUX. *Weisse nicht oxydirbare Metalllegirung für Fasshähne.* White, unoxidizable alloy for faucets. Dingler's *Journal*, vol. 178, 1865, p. 242.

Contains tin, antimony, and nickel.

WADE. Reports on Experiments on Metals for Cannon. By officers of the Ordnance Department, United States Army. 1 vol., Philadelphia, 1856.

Contains a valuable report by Major Wade, U. S. A., on the properties of bronze for cannon, with description of the testing apparatus used, effects of sudden cooling, separation of the metals, and discussion of results.

WATT'S. Watt's Dictionary of Chemistry Vol. 3, pp. 942–946. Articles on metals and alloys. See also under heads of the different metals.

WEIDEMANN and FRANZ. *Ueber die Wärme-Leitungsfähigkeit der Metalle.* On the heat conductivity of metals. By G. H. Weidemann and Rudolph Franz. Pogg. *Annalen*, vol. 89, 1853, pp. 497–531. Phil. Mag., vol. 7, 1854, pp. 33–39.

WEIDEMANN. *Ueber die Leitungsfähigkeit einiger Legirungen für Wärme und Elektricität* On the conductivity of some alloys for heat and electricity. By G. Weidemann. Pogg. *Annalen*, vol. 108, 1859, pp. 393–407. Phil. Mag., vol. 19, 1860, pp. 243, 244.

The order of conductivity of the metals was found to be the same for heat as for electricity.

WEISSENBORN. Weissenborn's American Locomotive Engineering contains table of useful alloys of copper, including those used in locomotives.

WERTHEIM. *De l'élasticité et de la tenacité des alliages.* On the elasticity and tenacity of alloys. By M. G. Wertheim. *Comptes Rendus*, vol. 15, 1842, p. 110; vol. 16, 1845, pp. 998–1000.

Experiments upon 54 binary and 9 ternary alloys, with a view to determine whether their elasticity and tenacity followed any general laws.

WÖHLER and MICHEL. *Ueber krystallisirte Verbindungen von Aluminium mit Metallen.* On crystallized compounds of aluminum with metals. Liebig's *Annalen*, vol. 115, 1860, pp. 102–105. Phil. Mag., vol. 20, 1860, p. 377. Erdmann's *Journal*, vol. 82, 1861, pp. 237, 238.

Alloys of aluminum with tungsten, molybdenum, manganese, iron, and nickel.

WOOD. New Fusible Metal. Jour. Frank. Inst., vol. 40, 1860, pp. 125–128. Phil. Mag., vol. 20, 1860, p. 403. Dingler's *Journal*, vol. 158, 1860, pp. 376, 377. U. S. patent, Mar. 20, 1860.

WRIGHT. Improvement in alloys of nickel, silver, and copper. U. S. patent. Journal of Applied Chemistry, vol. 8, 1873, p 158.

ARCHES ON THE ELASTICITY AND TENACITY OF THE ALLOYS.

By M. G. Wertheim.*

e numerous researches which have been undertaken on the me-
l properties of matter, the experimenters have for the most part
nfirmed the laws which analysis had already made known, or
ed the substances which are used in construction. Thus, while
ne hand the laws which govern slight changes of form and vibra-
ay be considered as perfectly well understood, and on the other
on, steel, wood, and stone have been carefully studied, the me-
l properties of bodies in general, and the laws which control the
ement of their molecules, when this displacement is no longer
ght compared to the distances which separate them, have been
wholly neglected.

onstancy or the variability of the coefficient of elasticity in the
ubstance under different circumstances, the changes that me-
l treatment, annealing, and elevation of temperature can pro-
he relation between the theoretical and the actual rapidity of the
the laws of permanent displacements, and the different positions
ibrium, the existence of a certain limit of elasticity and of a max-
longation, and finally the numerical values of all these quantities,
ir relations to the chemical nature of the material,† offer so many
ns which have not as yet been discussed by philosophers, or which
een solved in different ways. In this, the first memoir which I
e honor to submit to the judgment of the academy, I discuss only
ple metals. In a short recapitulation of work already accom-
I will mention first the experiments on the constancy of the co-
t of elasticity.

mb and Lagerhjelm have found the same coefficient of elasticity
and steel of the same sample, whatever the mechanical treat-
which they were subjected; M. Poncelet, on the contrary, rely-
the uniformity of known results, does not admit this constancy
r iron. The other metals have not yet been studied in this re-
M. Gerstner concludes from his experiments on steel bars, that
fficients of elasticity remain the same in the different positions of
rium of the bar.

ing over the differences which may be exhibited in the same metal

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ptes Rendus, vol. 15, 1842, p. 110.

months after the deposition of my packet, M. Masson presented to the academy
in which he seeks to establish by his own experiments on iron, copper, and
l by the experiments of Chladni on tin and silver, the following law: Multi-
he coefficients of elasticity of the simple bodies by a multiple or submultiple
equivalents, a constant number is obtained. M. Masson himself attributes
only to accident (*Annales de Chimie et de Physique*, 3 série, t. iii). I have
efore considered it necessary to repeat the above. It will be understood, further,
rtain agreement can always be obtained by choosing arbitrarily the whole
by which the atomic weights must be multiplied or divided.

on account of the variations in its density or because of its impurity, the coefficients of elasticity have been determined for lead, zinc, silver, platinum, copper, iron, and steel, by Coulomb, Barlow, Tredgold, Young, Rennie, Duleau, Navier, Lagerhjelm, Leslie, Gerstner, Sequin, Martin, Savart, Weber, Ardant, and by the royal commission of Hanover.

Chladni took the rapidity of sound on iron, copper, silver, and tin, and Savart on iron, steel, and copper. M. Masson made known the rapidities in zinc and lead.

These results form almost the whole of our experimental knowledge of elasticity in an ordinary temperature; the variations in elasticity caused by the elevation of the temperature have not yet been investigated.

The researches on the cohesion of the metals are much more numerous, but from their nature also less apt to give concordant results. It would take too long to repeat them here. I will only say further, that the influence of annealing on cohesion has been investigated by MM. Dufour, Baudrimont, and Karmarsch, and that of elevation of temperature upon the cohesion of iron by MM. Tredgold, Lagerhjelm, Trémery, Poirier, and Dufour. Finally, MM. Minard and Desormes have made known the diminution of cohesion produced by heat in lead, tin, and copper. My experiments have been on the homogeneous metals which I have myself reduced or analyzed, when it was impossible to obtain them perfectly pure; these were lead, tin, cadmium, gold, silver, zinc, platinum, copper, iron, and steel. Each metal was first melted, when possible, then rolled and drawn, and finally annealed. In each of these conditions its density was noted; then I determined its coefficient of elasticity and the rapidity of sound, by means of three different methods: by transverse vibrations, by longitudinal vibrations, and by elongation.

The number of transverse vibrations per second was determined by the method of sketching the vibrations, original with M. Duhamel. A little elastic bent wire attached to the top of the rod under examination left an impression upon a disk coated with lampblack. Having failed to give this disk a uniform rate of motion, I determined the length of the vibrations by comparing the vibrations of the rod with those of a standard fork made by M. Marloye, and making exactly 256 vibrations per second; the time was thus determined within at least $\frac{1}{2560}$ of a second.

The number of longitudinal vibrations was determined by means of a differential sonometer consonant with the same fork. I satisfied myself as to the exactitude of estimates by calculating directly the longitudinal vibrations drawn by two rods of two meters length. The difference was only between three and seven vibrations in a thousand. Finally, these rods and bars were submitted to the action of successively increasing loads in an apparatus which allowed of even quite heavy loads being put on or taken off with facility and without jar.

The total elongations (sets) were of two kinds, one which disappears with the removal of the charge, and another which is permanent. Each of these two parts was measured separately, by means of a cathetometer measuring hundredths of a millimeter. Thus, not only the coefficient of elasticity was determined anew in each position of equilibrium that the rod attained, but also all that relates to the limit of elasticity, to the maximum of elongation, and to cohesion, was studied at the same time. After rupture, the density and elasticity of the fragments were examined anew, and, finally, all the experiments in elongation were repeated at the temperatures of 100° and 200° C. These, then, are the conclusions that may be drawn from these experiments.

1st. The coefficient of elasticity is not constant for the same metal; whatever augments the density increases it, and reciprocally.

2d. The longitudinal and transverse vibrations evidently give the same coefficient of elasticity.

3d. The vibrations give coefficients of elasticity much greater than those obtained by elongation. This difference is due to the acceleration of movement produced by liberated heat.

4th. Consequently, sound in solid bodies is due to waves and condensation, and we may be able by means of the formula given by M. Duhamel to make use of the relation between actual and theoretical speeds of sound, to find out the relation of specific heat under constant pressure to that at constant volume. This ratio is greater for annealed than for non-annealed metals.

5th. The coefficient of elasticity diminishes with the elevation of the temperature at a more rapid rate than that which is due to the corresponding dilation.

6th. Magnetization does not sensibly change the elasticity of iron.

7th. The elongation of rods and bars by the application of loads affects their densities very slightly. The coefficient of elasticity should therefore vary as little in the different positions of equilibrium; and this is in fact what takes place, in so far as the loads do not become great enough to produce rupture. The law of Gerstner is therefore confirmed by all the metals of which the particles take a position of equilibrium after having passed their limit of elasticity.

8th. The permanent alloys are not found intermittently, but in a continuous manner. By suitably limiting the load and its duration of action, such permanent elongation as may be desired can be produced.

9th. No true limit of elasticity exists; and if no permanent elongation is observed for the first loads, it must be because they have not been allowed time to act, and because the rod submitted to the experiment is too short relatively to the delicacy of the measuring instrument.

The values of maximum elongation and of cohesion also depend much on the manner of operation. They become greater the more slowly the loads are increased. It may be seen from this how arbitrary is the determination of least and of greatest permanent elongation, and that we cannot, with Lagerhjelm, found a law upon their values.

10th. The resistance to rupture is considerably diminished by annealing. The elevation of the temperature even to 200° C. does not greatly diminish the cohesion of metals previously annealed.

After this purely experimental part, I sought to discover a relation between the coefficient of elasticity, which is the only truly scientific mechanical datum, and the molecular constitution for comparing the result of calculation with those of experiment.

M. Poisson has been led to the following expression of the coefficient of elasticity:

$$q=\frac{\pi}{g}\sum_{r=x}^{r=\infty}\frac{r^5}{a^5}\frac{d\frac{1}{r}fr}{dr},$$

in which a is the mean distance of the molecules, r the radius of action of the molecule, the function fr giving the result of simultaneous action of the attractive molecular force and of the repulsion due to heat.

To find a I assume that the weight of each molecule is expressed by its atomic weight. We know that this hypothesis is probable from the researches of MM. Dulong and Petit, Avogrado, Regnault, and Baudrimont, on specific heat.

The relative number of atoms contained in the same volume is then obtained by dividing the specific weight by the atomic weight; the reciprocal of the cube root of this number is the measure of the distance of the molecules for each metal in its different conditions—that is to say, the value of a.

There remains, then, in the formula to be determined, only the functions fr which we may attempt to deduce.

The following are the results of this formula:

1st. q should become greater when a diminishes, and reciprocally. It may be seen in the fourth table of my memoir that this really takes place, but the condensations and dilatations that we can produce by these mechanical means are too slight for us to determine with certainty the relation between the changes of a and q; nevertheless, the product qa^7 is very nearly constant for the same metal. With elevation of temperature the coefficient of elasticity diminishes so rapidly that the product qa^7 is always less than at an ordinary temperature; the function fr should then include temperature.

2d. The different metals follow in the same order in proximity of the molecules, in their coefficient of elasticity, and in their power to conduct sound in proportion to its intensity (this last is only approximately known by the experiments of Perolle). Platinum only ranks between copper and iron in relation to the coefficient of elasticity, while it ranks between zinc and copper in relation to the distances of the molecules.

3d. The product of the coefficient of elasticity by the seventh power of the mean relative distance of the molecules is the same for the greater part of the metals. This agreement is so complete that it can be exacted to this degree of approximation for lead, cadmium, gold, silver, zinc, and iron; but copper gives a somewhat smaller product, and tin and platinum much higher products, than the other metals. If this agreement were general, we might infer from it that the resultant of the attractive molecular force and heat repulsion diminishes in the inverse ratio of the fifth power of the distances. But this agreement is not confirmed by all the metals experimented upon, proving only that this resultant diminishes in fact, as we assume to be the case in our calculations, much more rapidly than in the inverse ratio of the square of the distances. In the letter attached to this memoir the author requests the opening of a sealed packet dated July 19, 1841. This packet, opened on the spot, contained the following note: "Sealed packet addressed by M. Wertheim in 1841, accepted by the academy at the session of July 9."

Philosophers generally admit that atomic weights represent the true weight of the molecules, and that the diameters of the molecules are variable in their ratio to the distances which separate them. We can then obtain the number of molecules of the different simple bodies contained in the unit of volume by dividing their specific weights by their atomic weights; as to composite bodies, this same reasoning will lead to a knowledge of their molecular arrangement. Now the attractive force should necessarily be a function of the distance, a function that experiment alone can make known, and which leads to the knowledge of the laws of cohesion, of elasticity, and of the rapidity of sound.

The comparison contained in the following table, which I communicated to M. d'Estinghausen, at Vienna, four years since, shows the intimate relation of these different quantities. The first column contains the specific weights of the melted metals; the second the atomic weights, calling the atomic weight of oxygen = 1; the third column contains the number of atoms in the unit of volume.

mic weights are those of M. Berzélius, except that of silver, educed one-half, conformably to the researches of MM. Dulong and of M. Regnault, on specific heat.

	S.	A.	S. A.	Resistance to rupture per millimeter.		Coefficient of elasticity. Tredgold.	Rapidity of sound. Chladni.
				By extension after Guyt-Morvean.	By compression after Reunie.		
.....	11.352	12.94498	0.8769	0.022	1.45	600	.....
.....	7.285	7.35294	0.9907	0.063	6.20	3.200	7.5
.....	19.258	12.43013	1.5493	0.274	.....	.....	.....
.....	10.542	6.75803	1.5599	0.341	.....	.....	9.0
.....	6.861	4.03226	1.7015	*0.199	.....	9.600	.....
.....	21.530	12.33499	1.7454	0.499	.....	.....	.....
.....	8.850	3.95695	2.2365	0.550	38.55	.....	12.0
.....	7.788	3.39205	2.2959	1.000	.....	20.000	17.0

nce of zinc is lower, which should not be according to its number of atoms; but this dis- y reasonably be attributed to the impurity of the metal experimented upon or to its ndition.

urther, that the metals range as to their conductibility for the of sound, according to Perolle: lead, tin, gold, silver, copper,

the diamond, hardest of the simple bodies, contains nearly nolecules as iron; its number is 4,668 to 4,708; these numbers ed by dividing its extreme specific weights, 3501–3531, by its ight, 75, recently determined by M. Dumas.

that in the simple bodies which have been submitted to experi- far, cohesion, elasticity, and conductibility of sound, as much d to its quickness as to its intensity, are as much greater as ules of the same bodies are nearer to one another at the same re.

experiments are far from being sufficiently exact to serve as a alculations. In fact only a small number of chemically impure ve been tested by the methods of extension and of rupture, n to me better adapted to researches on vibrations than to the nolecular forces. It was with this view that I made the exper- vibrations of bars of chemically-pure metals, the results of ave the honor to submit to the academy.

E ELASTICITY AND TENACITY OF THE ALLOYS.

By M. G. Wertheim.*

(Abstract by the author.)

vious work which I had the honor to present to the Academy session of July 18, 1842, I considered the mechanical proper- simple metals. After having examined and compared the nethods of studying elasticity in relation to ordinary as well temperatures, I applied these methods to the pure metals and results of which I will describe only those which serve as the ie new work.

* *Comptes Rendus*, vol. 16, 1845, pp. 978–1000.

It was shown by these experiments—

1st. That the coefficient of elasticity is not constant for the same metal, but that it changes with the density and in the same way.

2d. That the longitudinal and transverse vibrations produce a coefficient of elasticity a little greater than that deduced by direct elongation.

3d. That experiment agrees with analysis as to the relation which should exist between the coefficient of elasticity and the mean distance of the molecules; that is, whenever in the same metal this distance becomes greater the coefficient of elasticity diminishes, and reciprocally; consequently the different metals form the same series whether arranged according to their coefficients of elasticity, or according to the proximity of their molecules.

4th. That the product of the coefficient of elasticity by the seventh power of the mean relative distances of the molecules is the same for the greater part of the metals.

In this second paper which I have the honor to present to the Academy, my object is to see, first, if these laws are equally applicable to alloys. Then to ascertain whether the mechanical properties can assist us to an understanding of the arrangement of the molecules of the constituent metals of the alloys; and, finally, to seek for some relations between the properties of the alloys and those of the constituent metals.

In general, the alloys, in spite of their frequent employment in the arts, have not yet been studied as to their elasticity. The coefficients of elasticity of two alloys alone, that of brass and that of bell-metal, have been determined by Tredgold, Savart, Bevan, and Ardant.

The cohesion of the alloys, on the contrary, has been the object of a long series of experiments, especially on the part of Musschembroek and Karmasch, but yet no general law has been found. The alloys which I have used in my experiments have been prepared in part of the pure metals employed in my former researches, and in part of the pure metals of commerce. After mixing them well, I stirred them frequently while in fusion, then poured them. The ductile alloys were drawn, the others filed to the requisite size. I will not go into the details of these experiments, which were precisely similar to those made on simple metals, but only say that I feel bound to analyze chemically all the alloys, although I might have, for the most part, mixed the metals by atomic weights, or the simple multiples of those weights. But the unequal oxidization or the partial vaporization of a constituent has often and considerably changed the proportions.

When the alloys were composed of metals whose specific weights were very different, or when they offered inequalities of color or of malleability, I made the analysis on parts taken from the two extremities of the cast bar; consequently, with these analyses, I was obliged to reject a large number of non-homogeneous bars.

My experiments were made upon fifty-four binary alloys and nine ternary alloys, among which are found also most of the alloys employed in the arts, such as brass, pinchbeck, gong-metal annealed and unannealed, bronze, packfong, type-metal, &c.

These experiments gave the following results:

1st. If we suppose all the molecules of an alloy to be the same distance from one another, as seems natural, we find that the smaller the mean distance the greater is the coefficient of elasticity. We notice frequently some exceptions in the series of alloys, and further, the product qa^7 which is almost constant for simple metals, varies greatly in the alloys. It is possible that another hypothesis on the molecular arrangement will cause this objection to disappear.

d. The coefficient of elasticity of the alloys agrees sufficiently well h the mean of the coefficient of elasticity of the constituent metals, e alloys of zinc and copper being the only exceptions. The only densations and expansions which occur during the formation of the y do not sensibly affect the coefficient. We can then calculate be-hand what should be the composition of an alloy in order that it y have a given elasticity, or that it may conduct sound with a given idity, provided that this elasticity or this velocity fall within the its of the values of these same quantities for the known metals.

d. Neither the tenacity, nor the limit of elasticity, nor the maximum gation of an alloy can be determined *a priori* by means of the same ntities as determined for the metals which compose them.

th. The alloys act like the simple metals as to longitudinal and trans-se vibrations, as well as elongation.

RESEARCHES ON THE METALLIC ALLOYS.

By M. Alfred Riche.*

There is no study more generally neglected than that of the metallic oys. This very general neglect is due to the fact that the character-cs upon which we rely in determining the purity of substances are ally inapplicable to these substances. Their melting points, even, can-be determined, either because decomposition takes place before they ain their high temperature, or because we have no precise means for ermining such high temperatures.

n the second place their crystalline form is not a gauge of their ity, for Cooke and Matthiessen and de Bose have recently shown t the crystalline form of certain alloys does not vary even when 16 cent. of one of the two metals is substituted for 16 per cent. of the er.

Finally, liquation often prevents the precise determination of the nt at which the metal melts and solidifies. This latter property, vever, enabled M. Rudberg to prove the existence of true chemical binations among the numerous alloys of the two metals, but it can y be utilized in a few cases where the point to be determined is that the melting of alloys at low temperature. There is another charac-stic of which we take advantage in other cases, especially when we h to determine the combinations that water forms with the mineral ls; this is the maximum contraction.

t seems to me that this should be a characteristic of all the metals, there exist to my knowledge, at least, no data on the subject. It is y known that certain alloys are more dense really than they are the-tically, and that in others, on the contrary, the density given by ex-iment is less than the average density of the constituent metals.

I. *Alloys of tin and lead.*

sity of the melted tin employed	7.30
sity of the melted lead employed	11.364

The following table, of which the first column contains the theoretical sity of the alloys, the second their density as given by experiment, the third the difference between these two densities, shows that

* *Comptes Rendus*, vol. 55, 1862, pp. 143–147.

there is sometimes dilatation and sometimes contraction, and that the maximum of contraction corresponds exactly to the alloy $Sn^2 Pb$:

[The sign — indicates dilatation; the sign + indicates contraction.]

	Theoretical.	Experimental.	Difference.
	Density.	Density.	
$Sn^5 Pb$	8.047	8.046	−0.001
$Sn^4 Pb$	8.193	8.195	+0.002
$Sn^7 Pb^2$	8.289	8.2915	+0.0025
$Sn^3 Pb$	8.407	8.414	+0.007
$Sn^5 Pb^2$	8.562	8.565	+0.003
$Sn^2 Pb$	8.764	8.7662	+0.0022
$Sn^3 Pb^2$	9.044	9.046	+0.002
$Sn Pb$	9.455	9.451	−0.004
$Sn Pb^2$	10.115	10.110	−0.005
$Sn Pb^3$	10.437	10.419	−0.018

The differences being slight I made a large number of determinations, especially on the alloy $Sn^3 Pb$ and those near it; it is for this reason that I took the density of the alloys corresponding to the formulæ $Sn^7 Pb^2$ and $Sn^3 Pb^2$.

For the alloy $Sn^3 Pb$ alone I made seventeen determinations, which all gave numbers varying between 8,417 and 8,411. I worked each time upon newly prepared samples in quantities varying between 45 and 75 grammes at varying temperatures.

The alloys were prepared directly by melting in earthen crucibles, stirring carefully, then cooling in a long and narrow cast-iron ingot mold of such shape that solidification took place almost instantly, and consequently liquation did not affect the product obtained.

The density of the entire ingot, and not of a portion of it, was taken. The hydrostatic balance was employed. The numbers obtained correspond to the temperature of 18° C. Analysis of the alloy $Sn^3 Pb$ and of the alloys near it was afterward made, and the numbers given by experiment corresponded with the theoretical.

Is the alloy $Sn^3 Pb$ a distinct chemical compound? It seems to me unquestionable, for this is the point of saturation, the point of maximum contraction, and this point corresponds to an atomic combination.

Besides—and it is for this reason that I commenced my researches on the alloys of tin and lead which were the principal subject of the works of M. Rudberg—this alloy is the only chemical compound which he admits to exist between these two metals. Two different methods, then, lead to the same conclusion:

II. *Alloys of lead and bismuth.*

Density of the lead 11.364
Density of the bismuth 9.830

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
$Bi^2 Pb$	10.099	10.232	+0.133	
$Bi Pb$	10.288	10.519	+0.231	
$Bi Pb^2$	10.536	10.931	+0.395	
$Bi^3 Pb^5$	10.622	11.038	+0.416	
$Bi Pb^3$	10.448	11.108	+0.660	Maximum contraction.
$Bi^2 Pb^7$	10.748	11.166	+0.418	
$Bi Pb^4$	10.797	11.194	+0.397	
$Bi Pb^5$	10.874	11.209	+0.335	
$Bi Pb^6$	10.932	11.225	+0.293	
$Bi Pb^7$	10.979	11.235	+0.254	

ximum contraction, then, corresponds to the alloy Bi Pb^3, and side of this alloy a very regular diminution in contraction)ticed. The differences being very great both between the l and experimental density, and between the density of each that of its neighbors, I only made two determinations for each analysis of the ends and of the middle of the ingot formed by Bi Pb^3 gave the same numbers, it seems to me that this alloy considered as a chemical compound.

)erg did not experiment upon this alloy Bi Pb^3, which is of a hite, and formed entirely of little crystals. Distilled water with sufficient rapidity to give birth to little pearly white which are held in suspension in this liquid when it is stirred.

III. *Alloys of antimony and lead.*

he antimony 6.641
he lead 12.364

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
.....	7.237	7.214	−.023	
.....	7.385	7.361	−.024	
.....	7.651	7.622	−.029	
.....	8.271	8.233	−.038	
.....	9.046	8.999	−.047	Maximum dilatation.
.....	9.510	9.502	−.008	
.....	9.819	9.817	−.002	
.....	10.040	10.040	Nulle.	
.....	10.206	10.211	+.005	
.....	10.335	10.344	+.009	
.....	10.438	10.455	+.017	
.....	10.521	10.541	+.020	
.....	10.592	10.615	+.023	Maximum contraction
.....	10.652	10.673	+.021	
.....	10.702	10.722	+.020	
.....	10.746	10.764	+.018	
.....	10.785	10.802	+.017	

imum of contraction corresponds moreover to an atomic alloy hich has a rather simple composition, and near the alloy Sb maximum of dilatation. The phenomena are therefore more d than in the preceding cases.

loys are crystalline. The alloys near Sb Pb^2 crystallize in scales. The crystals of the following are very fine yet very

IV. *Alloys of tin and bismuth.*

een able to make but one series of experiments on pure bis- propose to prepare some anew in order to verify them.

	Theoretical.	Experimental.	Difference.	Remarks.
	Density.	Density.		
.....	9.426	9.434	+.008	
.....	9.135	9.145	+.010	
.....	8.740	8.754	+.014	
.....	8.491	8.506	+.015	
.....	8.306	8.327	+.021	
.....	8.174	8.199	+.025	Maximum contraction
.....	8.073	8.097	+.024	
.....	7.994	8.017	+.023	

imum of contraction, therefore, should take place in the alloy ich is a silvery-white metal formed of little crystalline grains d. This alloy was not attacked by distilled water; at the eral hours it retained its brilliancy and its silvery luster.

RESEARCHES ON THE ALLOYS.

By M. Alfred Riche.*

In this note, which is a summary of a general research on the alloys, I have to do only with the alloys of copper and tin with respect to their density, liquation, and fusibility.

Density.—The first determinations were made on bars weighing from 50 to 60 grammes, but no great importance can be attached to the results obtained on account of the considerable variations which exist in the texture of the different alloys, and for this reason I afterward worked with these materials reduced to fine powder. The subjoined table shows a new fact namely, that the contraction increases quite regularly from the alloys very rich in tin, up to the alloy $Sn\ Cu^2$, and that from this point it suddenly increases, attaining a maximum when the tin and copper are in the relation of 1:3. From this alloy the density diminishes, then again increases quite regularly, but the density of the alloys containing most copper is less than that of the alloy $Sn\ Cu^3$, which contains only 62 per cent. of copper. Besides, this alloy is clearly different from all the others in its characteristics; it is brittle enough to be pounded in a mortar, and is seen in bluish crystalline grains, which in no respect resemble tin or copper.

Density of the alloys of copper and tin.

Formula of the alloy.	Centesimal composition.	Density of the bars.	Density of the powders.		Calculated density.	Difference.
$Sn^3\ Cu$	Sn .... 90.27 Cu 9.73	7.52	7.23 7.32	7.28..	7.43	−0.15
$Sn^4\ Cu$	Sn .... 88.16 Cu 11.84	7.50	7.04 7.58	7.31..	7.46	−0.15
$Sn^3\ Cu$	Sn .... 84.79 Cu 15.21	7.53	7.43 7.44	7.44..	7.50	−0.06
$Sn^2\ Cu$	Sn .... 78.79 Cu 21.21	7.74	7.81 7.84	7.83..	7.58	+0.25
$Sn\ Cu$	Sn .... 65.01 Cu 34.99	8.12	7.93 7.87	7.90..	7.79	+0.11
$Sn^2\ Cu^3$	Sn .... 55.33 Cu 44.67	8.30	8.00 8.11	8.06..	7.93	+0.13
$Sn\ Cu^2$	Sn .... 48.16 Cu 51.84	8.57	8.07 8.23	8.15..	8.04	+0.11
$Sn\ Cu^3$	Sn .... 38.21 Cu 61.79	8.96	8.86–8.84–8.99 8.93–8.92–8.90	8.91..	8.21	+0.70
$Sn\ Cu^4$	Sn .... 31.72 Cu 68.28	8.80	8.65–8.85 8.80	8.77..	8.32	+0.45
$Sn\ Cu^5$	Sn .... 27.09 Cu 72.91	8.87	8.73–8.59 8.51–8.65	8.62..	8.40	+0.22
$Sn\ Cu^6$	Sn .... 23.69 Cu 76.31	8.91	8.54 8.77	8.65..	8.46	+0.19
$Sn\ Cu^7$	Sn .... 20.98 Cu 79.02	8.90	8.67 8.77	8.72..	8.50	+0.22
$Sn\ Cu^8$	Sn .... 18.85 Cu 81.15	8.86	9.06–8.62 8.83	8.84..	8.54	+0.30
$Sn\ Cu^{10}$	Sn .... 15.67 Cu 84.33	8.83	8.72–9.04 8.98–8.73	8.87..	8.60	+0.27
$Sn\ Cu^{15}$, cannon-bronze	Sn .... 11.00 Cu 89.00	8.80	8.97–8.74 8.81	8.84..	8.69	+0.15

Liquation.—The separation of the alloys into other alloys at the moment of solidification is not as marked as that of the alloys of silver and copper. In order to show this characteristic, the material must be stirred at the moment of solidification in order to separate the little drops of metal from the crystals already formed.

Annales de Chimie, vol. 30, 1873, pp. 351–419; Dingler's *Journal*, vols. 213, 214, 1874.

The following results were obtained on the last sample left liquid in a mass weighing 1,000 to 1,200 grammes:

Formula of the alloy.	Calculated weight of tin.	Weight of tin as found.	Formula of the alloy.	Calculated weight of tin.	Weight of tin as found.
$Sn^5 Cu$	90.27	98.50	$Sn Cu^5$	27.09	27.76
$Sn^4 Cu$	84.79	96.99	$Sn Cu^6$	23.69	25.17
$Sn^3 Cu$	78.79	94.40	$Sn Cu^7$	19.98	24.85
$Sn Cu$	65.01	82.83	$Sn Cu^8$	18.85	24.62
$Sn Cu^2$	46.49	50.42	$Sn Cu^{15}$	15.67	24.50
$Sn Cu^3$	37.37	37.29	$Sn Cu^{15}$	11.00	14.35
$Sn Cu^4$	31.72	31.15			

Consequently, liquation is exhibited by all the alloys except $Sn Cu^3$ and $Sn Cu^4$.

Fusibility.—In order to determine the fusibility of the alloys, I have recourse to the thermo-electric couple of platinum and palladium of M. Becquerel. This apparatus was made by M. Ruhmkorff. It may render great service to chemists, and is already employed in the metal foundery and in the pottery manufactory; but instead of using an ordinary galvanometer, I employed Weber's needle, which is much more sensitive.

I worked ordinarily on the preceding alloys and on the metals of which the points of fusion and of ebullition have been taken as fixed points by various experimenters.

From the numerous determinations that I made, it follows that the solidification of the alloys $Sn Cu^3$ and $Sn Cu^4$ took place at a temperature intermediate between the point of fusion of antimony and the boiling point of cadmium.

Boiling water under a pressure of 76 centimeters	24
Solidification of tin	57
Solidification of antimony	206
Solidification of $Sn Cu^3$	247
Solidification of $Sn Cu^4$	265
Ebullition of cadmium	335

I tried this determination on all the preceding alloys, and will give the results in the detailed memoir; but it is clear that, on account of liquation, we can obtain an exact result only with the alloys $Sn Cu^3$ and $Sn Cu^4$, in which there is no sensible liquation.

In a previous paper I gave the fusibility and density of the bronzes, and I showed that the alloy $Sn Cu^3$ does not separate into other compounds even when it is kept melted and stirred for a long time. I stated, as Calvert and Johnson had previously shown, that copper and tin exhibit maximum contraction in this alloy, contrary to the opinion of other experimenters, who have maintained that contraction increases with the proportion of tin.*

The errors on this point and the differences which exist between the numbers obtained by Calvert and Johnson and mine are probably due to the fact that I worked on alloys reduced to fine powders, while the other experimenters, and probably the able English authorities themselves, made use of ingot metal. Now, supposing that they avoided the formation of blowholes in cooling, the texture of the alloys presents such differences, and the density of certain bronzes varies so greatly with the rapidity of cooling, that the materials cannot be compared if plates or ingots are employed.

I. Caron, in his celebrated researches on steel, has undoubtedly proved that tempering diminishes the density of this body. It is said that the same is true of the bronze of sonorous instruments.† My experiments, recapitulated in the following table, show the contrary.

* Briche, *Traité de Chimie de M. Dumas*, t. iii, p. 512.

† Dusaussoy, *Traité de Chimie de M. Dumas*, t. iii, p. 517. Wertheim, *Annales de Chim. et de Phys.*, 3d série, t. xii, p. 593.

Then, tempering and annealing produce entirely different effects upon steel and upon bronze; while tempering diminishes the density of the former, it increases the density of the latter. The fact is no more than natural, for tempering hardens wrought steel, while it softens bronze. As to annealing, it increases the density of tempered steel, while it diminishes the density of tempered bronze.

Huntsmann steel used in making coin at the mint of Paris.

Number of order.	Density of cast bars.	Density after annealing.	Density after tempering.	Density after annealing and tempering.	Density after tempering and annealing.
1	7.841	7.843	.....	7.758	.....
2	7.841	7.843	.....	7.735	.....
3	7.839	7.845	.....	7.763	.....
4	7.839	7.842	.....	7.705	.....
5	7.839	.....	7.735	.....	7.831
6	7.846	.....	7.749	.....	7.833
7	7.839	.....	7.738	.....	7.829

Bronze at 20 per cent. (sonorous instruments).

Number of order.	Density after casting.	Density after tempering.	Density after annealing.	Density after tempering and annealing.	Density after annealing and tempering.	Density after tempering, annealing, and second tempering.	Density after annealing, tempering, and second annealing.	Density after 2 annealings and 2 temperings.	Density after 2 annealings, 2 temperings, and a third annealing.
1	8.787	8.823	.....	8.817	.....	8.849	.....	.....	.....
2	8.858	8.915	.....	8.907	.....	8.927	.....	.....	.....
3	8.826	8.863	.....	8.847	.....	8.874	.....	.....	.....
4	8.862	8.796	.....	8.886	.....	8.907	.....	.....	.....
5	8.863	8.906	.....	8.894	.....	8.922	.....	.....	.....
6	8.737	.....	8.733	.....	8.763	.....	8.753	8.775	8.788
7	8.873	.....	8.782	.....	8.911	.....	8.889	8.926	8.927

II. In view of these results, it will be interesting to know whether these differences are shown when the materials are subjected to hammering or to the press. The following table shows the variations in density when steel and bronze are subjected to the successive action of blow and of heat:*

	Steel.		Bronze.	
	I.	II.	Tempering.	Annealing.
Initial density	7.845	7.847	8.527	8.[illegible]
Density after action of fire	7.849	7.849	8.543	8.[illegible]
Density after first blow	7.839	7.843	8.771	8.[illegible]
Density after second action of fire	7.844	7.843	8.777	8.[illegible]
Density after second blow	7.838	7.839	8.871	8.[illegible]
Density after third action of fire	7.844	7.845	8.877	.....
Density after third blow	7.837	7.841	8.918	.....
Density after fourth action of fire	7.849	7.854	8.927	.....
Density after fourth blow	7.849	7.849	8.937	.....
Density after fifth action of fire	7.844	7.845	8.945	.....

*These metals were in sheets weighing from 80 to 150 grammes. They were struck under a press worked by four men. The steel had been annealed. The bronze had been tempered in some experiments and annealed in others. The materials were placed in the same sheet-iron case, surrounded with coal dust.

Hence, blows act very differently on bronze and on steel. They considerably increase the density of the former, while they produce scarcely ny sensible difference in steel, though the tendency is to diminish its ensity. If this latter effect is realized in all the conditions of the blow or steel, we may conclude that the blow produces in these two cases he same result as tempering. The fact is unquestionable for bronze t least; and as in this case the action of heat and of blows tend both n the same direction, the density increases considerably; indeed, after ve temperings the density increased nearly one-twentieth.

We see, then, how on the one hand a block of steel subjected to impression in making coin undergoes thirty and even sixty annealings ithout being affected; and we see on the other hand how all the atempts made in our country to manufacture tamtams and cymbals with he metal of the Chinese and Turks have been unsuccessful, for the metal nce melted it was made red-hot or tempered, and then worked *cold;** ll operations which contract the metal, and make it liable to fracture uring the working.

In order to succeed, the Oriental method of working must be exactly llowed. Now, we understand this method perfectly, thanks to various ravelers, and especially to M. Champion, of the *Conservatoire des Arts Metiers*, who describes the operation in all its details in a work which ill shortly be published. This method is very reasonable. Every part f the work which has for its object the thinning of the cast metal is one by rapid hammering at a high temperature. The dilatation produced by heat counterbalances the contraction caused by the hammering.

III. Copper subjected to successive tempering and annealing presents othing similar. The density scarcely varies. It falls a little, for after even operations it was reduced from 8.921 to 8.781. No marked difference can be observed in the effect of tempering and annealing. It is he same for the bronzes containing but little tin.

If in making copper medals, the medal still *red-hot* be plunged into cidulated water, it is simply to avoid the considerable oxydization produced by slow cooling in contact with air.

I had some copper medals struck, and determined the density after ach compression and after each cooling. I found that after six operaons the density had again become what it was after casting. This eculiarity and the softness of the copper make this metal one especially dapted to making medals.

Analyses of antique medals show that the ancients sometimes employed opper for this purpose, but generally bronze, and that the proportion f tin varied between one and twenty per cent.

After having discovered, by means of an ingenious apparatus made by . Magna, that bronzes containing two to four per cent. of tin are not nch harder than copper, I had some medals of copper and of other alys struck, without any difference in the mode of working. The differnces were not very noticeable for medals of 35 millimeters and under, nt became very marked in strips of 50 and 68 centimeters.

While in making a medal the copper had to undergo but 7 compresons and 7 annealings, there were required 10 for bronze of 97 of copper nd 3 of tin; 12 for bronze of 96 of copper and 3.5 of tin; 13 to 14 for ronze of 96 of copper and 4 of tin; 16 at least for bronze of 95 of copper and 5 of tin.

* We read, it is true, in several works on chemistry, that this method is satisfactory. ur best manufacturers, M. Lecomte and M. Gautrot, assured me that no one had yet ceeded in making tamtams and cymbals with the metal of the Orientals. (C. R., 69, Semestre, t. lxix, No. 5.)

The introduction of zinc softens the metal slightly, for 14 compressions were suffcient to make the same medal with an alloy containing 95 copper, 4 tin, 1 zinc, and 16 to 18 were necessary with an alloy containing 94 copper, 4 tin, and 2 zinc, which was formerly employed.

Very important works on the alloys have been published within a few years by MM. Wertheim, Levol, Matthiessen, Calvert and Johnson, &c. Yet we are far from understanding satisfactorily the general properties of the more important classes of these bodies, such as bronze and brass, and I have devoted myself to filling up some of the gaps in our knowledge of these subjects. In this first paper I consider more especially the alloys of copper and tin with reference to their fusibility, liquation, and the modifications which take place in their volume, under the influences of annealing, heating, and mechanical action. Afterwards, I speak more briefly of copper, of its alloys with zinc, aluminium, nickel, and iron, and finally I compare these bodies with steel, iron, and glass, with reference to the variation in volume that tempering and annealing produce in these different substances.

The determination of the mechanical properties remained to be considered. Not having at my disposal the necessary apparatus, I applied to M. Tresca, who has established at the "*Conservatoire des Arts et Metiers*" special apparatus for this sort of experiments, and I shall shortly publish, in common with M. Alfred Tresca, the second part of this work, including the study of the mechanical properties of copper, tin, zinc, and their principal alloys, prepared in atomic proportions.

§ I.—FUSIBILITY OF SOME METALS AND ALLOYS.

Liquation of bronze.

I have tried various means to determine the fusibility of metals which melt at high temperatures, and it seems to me that only one can be practically applied and furnish sufficiently exact results; this is the thermo-electric pyrometer, formed by the junction of a wire of platinum and one of palladium (an apparatus proposed in 1835 by M. Becquerel, senior, and carefully considered by M. Edmond Becquerel in 1863).

This instrument allows of the temperature being measured by comparing the deviation produced at the moment when the matter solidifies or melts, with the deviation observed in baths having a fixed temperature. This pyrometer, so graduated, may be of great service in chemical and industrial pursuits. M. Ruhmkorff, who makes these instruments, has introduced them into the establishments of the founders and pottery manufacturers.

The needle employed in manufactures is an ordinary one, but for researches, where precision is required, it is necessary to make use of Weber's, which I have employed. The only difficulty—and it is a very serious one—is in finding a position for it where it will not shake or tremble.

I use at least one kilogram of alloy. When it is fusible at a low temperature it is heated in a crucible in which the porcelain tube containing the pyrometer is placed. When it melts at a high temperature it is first raised to that point in a blast-furnace, and the crucible of molten metal is placed in an ordinary laboratory furnace where it is slowly cooled. The pyrometric tube previously heated is then introduced into the bath, and the deviation at the moment of solidification is noted.

All the alloys of copper and tin are subject to liquation at the moment of solidification save those of which the composition corresponds to the

formulæ Sn Cu^3 and Sn Cu^4. The liquation is slight for the alloy in which tin and copper are in the relation of 1:15, and considerable for the others, in such degree that it is impossible to determine the fusibility of any except the alloys Sn Cu^3 and Sn Cu^4.

Three series of experiments have been made. In the last two the wire wound around the bobbin of the galvanometer was much longer, and in one section ten times smaller than the wire which had been used in the former series.

This modification in the apparatus was made in order to increase the resistance of the thermo-electric circuit without reducing the sensitiveness of the instrument, and to lessen by this means the error which results from the variation in conductibility in the circuit, which is caused by variations of temperature.

Each day, at the beginning and at the close of the experiments, those results only were considered good which were obtained when the deviation was obviously the same in these two experiments.

M. Edmond Becquerel was very desirous of verifying my principal results with my pyrometer, and he found them proportional to the results obtained by him for the same bodies.

TABLE 1.

	Fixed points	Deviations observed.			Relation of experiments II and III.
		I.	II.	III.	
Water boils	100° C.	23	19	10.5	1.81
Tin solidifies	228	57	46.5	24.2	1.92
Lead solidifies	228	89	59	32.0	1.84
Mercury boils	358	91	81	42.5	1.90
Sulphur boils	445	123	104	55.0	1.89
Antimony solidifies	†584	206	181	95.0	1.90
Alloy Sn Cu^3 solidifies	584	247	200	106.0	1.88
Alloy Sn Cu^4 solidifies	584	265	200	106.0	1.88
Cadmium boils	‡720	335	200	115.0	1.88
Coin silver (·999) solidifies	720	399	392	207.0	1.89
Cannon bronze solidifies	720	†406	392	207.0	1.89
Gold (·899) solidifies	720	448	392	207.0	1.89
Copper solidifies	720	475	435	233.0	1.86

† M. Becquerel.
‡ Approximate result.

I made a large number of experiments specially to determine the comparative fusibility of the alloys of tin and copper. They have always agreed with Sn Cu^4, and especially with Sn Cu^3, and have been very irregular with the others. These latter results are caused by the liquation of the alloys at the moment of solidification. In order to determine within what limits copper and tin separate from their alloys I first proposed to melt them in an iron ingot mold, as Levol did some large spherical masses, and analyze the different parts, but with one part the liquated alloy is not very hard, and with another part the proceeds of the mixture have not the sharpness of those resulting from the tests of the alloys of gold and silver, and I was obliged to give it up after a number of unsuccessful attempts.

Two series of experiments have been made:

1st. From 500 to 700 grammes of alloy were melted in cylindrical earthen tubes of three centimeters diameter and sixty centimeters in height.

The alloy was kept in the tube in a liquid state for ten hours, and left to cool very slowly in the middle of the hearth, covered with ashes.

To avoid oxidation the tubes were inclosed in a large earthen box where they were separated by coal-dust, and in each tube was placed coal, which floated over the metallic bath. When the ingot was cool the tubes were broken, and a portion taken from the top and the bottom of each alloy for trial.

2d. From 500 to 700 grammes of each alloy were melted in an earthen crucible and stirred constantly with an earthenware rod until solidification took place, so that the liquid portion did not remain viscous in the midst of the solidified mass. Then the portion subjected to analysis was poured off.

The following table shows that all the alloys of copper and of tin are subject to liquation, except those which correspond to the formulæ $Sn\,Cu^3$ and $Sn\,Cu^4$, which explains the impossibility of determining the point of fusion of any except these two. The liquation is greater in the alloys rich in tin than in those in which copper predominates; for it is only in the former that it has been possible to observe the different compositions at the top and bottom of the ingots obtained after long fusion followed by slow cooling.

TABLE 2.

Number of order.	Composition of alloy.	Quantity of tin; per cent. at the top and bottom of the bar.		Quantity of tin; per cent. found in the product last solidified.	Physical characteristics.
		Bottom.	*Top.*		
1	$Sn^5\,Cu$ { Cu ... 9.73 / Sn^5 ... 90.27 }	87.87	92.99	98.50	Tin gray; soft, like that metal; non-crystalline.
2	$Sn^3\,Cu$ { Cu .... 15.21 / Sn^3 ... 84.79 }	83.15	78.90	96.99	Tin gray; crystallizes when cooled slowly.
3	$Sn^2\,Cu$ { Cu ... 21.21 / Sn^2.... 78.79 }	81.81 74.97	84.56 77.40	94.40	Tin gray; crystallized; quite hard.
4	Sn Cu { Cu .... 34.99 / Sn .... 65.01 }	58.11 From 55 to 80	75.83	82.83	Whitish gray; crystallized; brittle.
5	$Sn\,Cu^2$ { Cu^2 ... 51.84 / Sn .... 48.16 }	Assay lost.....		40.52	Bluish gray; like zinc; very crystalline; very brittle.
6	$Sn\,Cu^3$ { Cu^3 ... 61.79 / Sn .... 38.21 }	37.29	37.66	*37.37 †37.30	Fine-grained; can be pounded in a mortar.
7	$Sn\,Cu^4$ { Cu^4 ... 68.28 / Sn .... 31.72 }	30.44	30.83	30.91	White; foliated; fragile as glass.
8	$Sn\,Cu^5$ { Cu^5 ... 72.91 / Sn .... 27.09 }	27.15	26.78	27.76	White, with yellowish reflections; crystalline; very hard.
9	$Sn\,Cu^6$ { Cu^6 ... 76.31 / Sn .... 23.69 }	23.37	23.69	25.17	Yellowish; fine-grained; very hard; malleable to dark red.
10	$Sn\,Cu^7$ { Cu^7 ... 79.02 / Sn .... 20.98 }	21.00	21.32	21.85	Physical properties like the preceding.
11	$Sn\,Cu^8$ { Cu^8 ... 81.15 / Sn .... 18.85 }	18.88	18.56	24.60	Physical properties like the preceding two.
12	$Sn\,Cu^{10}$ { Cu^{10}... 84.33 / Sn .... 15.67 }	15.18	15.18	20.06 24.50	Yellow; extremely tenacious.
13	$Sn\,Cu^{15}$ { Cu^{15}... 89.00 / Sn .... 11.00 }	15.18	15.18	13.10	Cannon bronze.

* Before fusion. † After 4 fusions in air.

§ II. DENSITY OF THE ALLOYS OF COPPER AND TIN.

My first experiments were made on bars of different alloys, but it should be remarked that even supposing it were possible to avoid all blowholes in the cooling, it is impossible to obtain comparable results because of variations in the texture of the bronzes. Some are not crystalline, others have a very fine grain, and some are in large, thin, tabular crystals. The bars on which I experimented in the former assays weighed between sixty and seventy grammes. They were melted in the

same mold. In the second series of experiments, filings were taken from top and bottom of the ingots which had been used in the preceding trials, in order to make two comparable assays for every alloy. These filings were made with a new file, and were afterwards submitted to the action of a magnet in order to separate the particles of iron that might have been detached from the file. The density was estimated in this latter case by a hydrometer. In one case the filings being placed in this vessel, the water was raised to the boiling point, and then it was kept several hours in vacuum.

The following table recapitulates these determinations:

TABLE 3.

Formula of the alloy.	Centesimal composition.	Density of the bars.	Density of the filings.		Calculated density.	Difference.
$Sn^5 Cu$	Sn ....90.27 Cu 9.73	7.52	7.23 7.32	7.28..	7.43	−0.15
$Sn^4 Cu$	Sn ....88.16 Cu 11.84	7.50	7.04 7.58	7.31..	7.46	−0.15
$Sn^3 Cu$	Sn ....84.79 Cu 15.21	7.53	7.43 7.44	7.44..	7.50	−0.06
$Sn^2 Cu$	Sn ....78.79 Cu 21.21	7.74	7.35 7.84	7.59..	7.58	+0.01
Sn Cu	Sn ....65.01 Cu 34.99	8.12	7.93 7.87	7.90..	7.79	+0.11
$Sn^2 Cu^3$	Sn ....55.33 Cu 44.67	8.30	8.00 8.11	8.06..	7.93	+0.13
$Sn Cu^2$	Sn ....48.16 Cu 51.84	8.57	8.07 8.23	8.15..	8.04	+0.11
$Sn Cu^3$	Sn ....38.21 Cu 61.79	8.96	8.86–8.84–8.99 8.93–8.92–8.90	8.91..	8.21	+0.70
$Sn Cu^4$	Sn ....31.72 Cu 68.28	8.80	8.61–8.85 8.80	8.75..	8.32	+0.43
$Sn Cu^5$	Sn .... 27.09 Cu 72.91	8.87	8.73–8.59 8.51–8.65	8.62..	8.40	+0.22
$Sn Cu^6$	Sn ....23.69 Cu 76.31	8.91	8.77–8.85 8.54	8.72..	8.46	+0.26
$Sn Cu^7$	Sn ....20.98 Cu 79.02	8.90	8.67 8.77	8.72.	8.50	+0.22
$Sn Cu^8$	Sn ....18.85 Cu 81.15	8.86	9.06–8.62 8.83	8.84..	8.54	+0.30
$Sn Cu^{10}$	Sn ....15.67 Cu 84.33	8.83	8.72–9.04 8.98–8.73	8.87..	8.60	+0.27
$Sn Cu^{15}$	Sn ....11.00 Cu 89.00	8.80	8.97–8.74 8.81	8.84..	8.69	+0.15

It was my intention to bring these densities back again to zero, but the uncertainty which prevails as to the value of the coefficients of dilatation of the metals, and the differences that they present according to the condition in which the metal is found, either free or combined, have led me to give the numbers which have been deduced by experiment.

These results verify the known fact that copper and tin contract in uniting. Still, when the proportion of tin is very great, the reverse seems to take place, but the difference is very slight. It is an undoubted fact that the contraction is very slight and regular up to the alloy $Sn Cu^2$; that from this point it increases suddenly till it reaches a maximum, when the copper and tin are in the relation of 3 to 1. The existence of this maximum of contraction had been previously announced by Calvert and Johnson,* contrary to the opinion of other experimenters who had maintained that the contraction increases with the proportion of tin.†

The errors on this point, and the differences which exist between certain numbers of Calvert and Johnson, are explained by §§ IV and V,

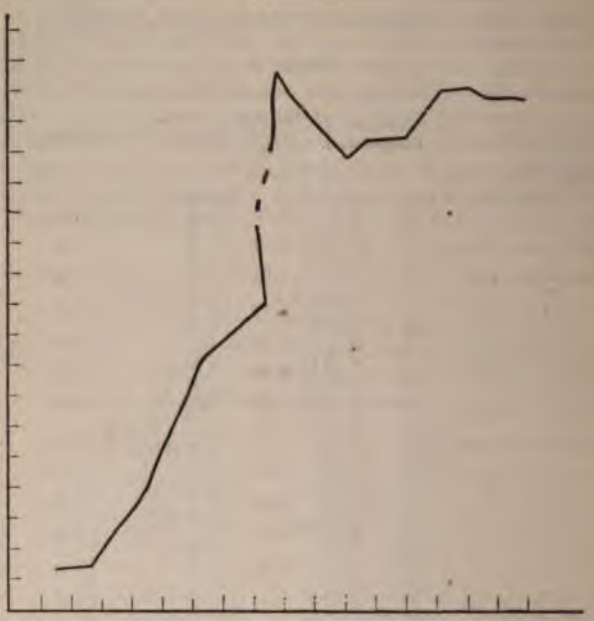
* Calvert and Johnson, *Moniteur Scientifique* t. iv, p. 225, 1862.

† Briche, *Traité de Chimie appliquée aux Arts*, Dumas, t. iii, p. 517.

and by the fact that former experimenters, and the able English chemists themselves, worked upon ingots and not upon filings.

To begin with the alloy Sn Cu^3, the density first diminishes and then increases quite regularly; but the density of the alloys richer in copper, as cannon bronze, is inferior to that of the alloy Sn Cu^3, which, however, contains only 61.79 per cent. of copper. The curve shown in the following table gives an idea of these variations in density:

TABLE 4.



Curve representing the comparative densities of the alloys of copper and tin.

It will be noticed that a great number of assays have been made for the alloy Sn Cu^3 and that all are concordant; that the density of the bar verifies the results obtained with matter in grain and in powder. The other properties of this alloy are equally exceptional. While all the preceding have the gray hue of tin, and while those that follow are white or yellow, this alone is distinguished by a bluish color. It exhibits no liquation, for after four successive fusions the last solidified product possessed the composition that it had immediately after the first casting.

Consequently the alloy Sn Cu^3 is, in the series of alloys of copper and tin, what the alloy Ag^3 Cu^4 is in the series of alloys of copper and silver as shown by Levol.*

§ III. HARDNESS.

I have tried various methods for comparing the alloys of copper and tin in respect to their hardness. None have given sufficiently satisfactory results to enable me to express their relative hardness by numbers. I finally made use of an apparatus invented by an ingenious engineer of

* *Annales de Chim. et de Phys.*, 3d série, t. xxxvi, p. 193.

Paris, M. Magna, an apparatus which, since my experiments, has been used to test rails on an Eastern railroad.

It consists of a weight, which slides without sensible friction in an iron tube, where it can be made to fall from a variable and determined height. This weight strikes a punch of tempered steel, which rests upon the specimen to be tested. This specimen is firmly fastened upon a block of steel attached to the tube and resting upon a block of wood.

But very imperfect comparisons are obtained, because the same shock produces a considerable impression on a soft alloy, and a scarcely observable dint, which is very difficult to measure, on a hard alloy. If, to avoid this difficulty, we strike a large number of blows, the metal hardens, and from thirty to sixty blows produce only insignificant results.

We cannot expect to destroy the effect of the compression by annealing, because the depths of the impression produced are variable and the surfaces distorted, when they should be plane and parallel. We can, at most, compare by this means, as we shall see farther on, only metals differing but little in hardness. I can only say that the hardness determined by this means increases from tin to the alloy containing copper and tin in the relation of equivalents.

From this alloy up to that which corresponds to the formula $Sn\ Cu^5$ the metal is too brittle to be assayed. The hardness of the bronze of sonorous instruments is such, that the punch is not sensibly injured by 100 successive shocks, or else it is shattered.

Hardness diminishes from this alloy to copper.

We will now examine particularly the cannon bronzes.

§ IV. BRONZE USED IN MAKING SONOROUS INSTRUMENTS.

$$\begin{aligned} Cu &= 78 \text{ to } 82 \\ Sn &= 22 \text{ to } 18 \\ \hline & 100 \end{aligned}$$

D'Arcet having proved that this bronze, unlike steel, is softened by tempering and hardened by annealing, it was proposed to determine the modification which its volume undergoes in tempering, annealing, and mechanical action.

1. *Alternate tempering and annealing.*

Ingots of this bronze were melted at a sufficiently high temperature in a cylindrical iron ingot-mould. Solidification took place in a few seconds. For the fusion, the copper was first heated alone in an earthern crucible; two or three pieces of coal were put into this vessel to avoid oxydization. When the copper was melted the tin was put in, and being stirred a little, it melted almost immediately. The ingots were cut and then carefully filed. As in all the following experiments the work was performed in the same way, we will describe it once for all.

The density was determined in all the experiments with two exact balances. That used for weighing in water had been made especially for that use at the laboratory of the mint. Boiling water was used, and the ingots were suspended by a horse hair, the trifling weight of which (0^{gr} 0.17 to 0^{gr} 0.20) was deducted.

The temperature at which most of the following determinations were made necessarily varied, but for each series of experiments the temperature did not vary more than three degrees, the balances being placed in an isolated and very cool position. The weight of the specimens was comparatively large, and varied frequently within the somewhat ex-

tended limits. In the first series of experiments each ingot weighed from 85 to 90 grammes. The specimens to be tempered and annealed were placed side by side in a sheet-iron box placed in another of cast-iron filled with coal dross, and covered with a cast-iron plate. When the metals were observably red, those which were to be tempered were plunged into cool water, and the interior case again closed, recovered with coal dross, and the whole left to cool slowly, the fire being covered with ashes.

This was done in the evening, and the specimens were not taken out again till the next day, and then they were so warm that they could hardly be held in the hand.

TABLE 5.

Bronze at 20.80 per cent. of tin.

	Density.									
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
After casting	8.787	8.858	8.825	8.862	8.863	8.780	8.715	8.822	8.842	8.747
After tempering	8.823	8.915	8.863	8.896	8.906	.....	.....	.....	.....	.....
After annealing	8.817	8.907	8.847	8.886	8.894	8.808	8.739	8.844	8.863	8.871
After tempering	8.849	8.927	8.874	8.907	8.922	.....	.....	.....	.....	.....

TABLE 6.

Bronze at 18 per cent. of tin.

	Density.	
	I. P=71^{gr}.490.	II. P=86^{gr}.775.
After casting	8.737	8.873
After annealing	8.733	8.863
After tempering	8.763	8.911
After annealing	8.753	8.889
After tempering	8.775	8.926
After tempering	8.786	8.927

A bar of two kilogrammes was melted in order to obtain some very homogeneous matter, because in the preceding experiment, where the operations had been carried on with only a little metal, the cooling had been made too rapid by the addition of tin, and it was made very hot before the tin was put in. The bar was cut into strips, and we experimented upon four of them.

TABLE 7.

Bronze at 20 per cent. of tin.

	Density.	
	I. P=132^{gr}.735.	II. P=128^{gr}.885.
After tempering	8.704	8.719
After annealing	8.712	8.728
After tempering	8.730	8.747
After annealing	8.724	8.744
After tempering	8.756	8.763
After annealing	8.741	8.759
After a second annealing	8.751	8.769
After tempering	8.775	8.792

TABLE 7—Continued.

	III. P=136gr.572.	IV. P=136gr.494.
er annealing	8.752	8.686
er tempering	8.780	8.713
er annealing	8.777	8.714
er tempering	8.804	8.736
er annealing	8.815	8.750
er tempering	8.841	8.774
er a second tempering	8.850	8.787
er annealing	8.807	8.760

It is evident from these three series of experiments that tempering gments considerably the density of bronze rich in tin, and that anneal- evidently diminishes the density of tempered bronze. Still the effect slow cooling by no means destroys the effect of tempering, for the nsity continues to increase till it becomes remarkable.

2. *Alternate action of heat of shock and of compression.*

The four preceding specimens were submitted to the action of the screw- ss, but as this bronze is brittle, it was merely compressed strongly the exertions of six men, instead of giving it a sudden blow. The two npered pieces resisted. The two annealed pieces were broken, giving, one a fragment weighing 80gr.335, and the other a fragment weigh- 64gr.644, with which we worked. Two samples were successively nealed; two others successively tempered. The results are given in following table:

TABLE 8.

	Density.			Density.	
	I. P=128gr.238.	II. P=64gr.644.		III. P=121gr.537.	IV. P=80gr.335.
er compression	8.796	8.775	After compression	8.782	8.792
er tempering	8.804	8.804	After annealing	8.767	8.803
er compression	8.805	8.789	After compression	*8.760	†8.796
er tempering	8.809	8.826	After annealing	8.763	8.814
er compression	8.818	8.840	After compression	‡8.766	8.812
er tempering	8.819	8.845	After annealing	8.772	8.824
er compression	8.827	8.865	After compression	8.776	8.817
er tempering	8.828	8.866	After annealing	8.788	8.844
er compression	8.837	8.889	After compression	8.795	8.835
er tempering	8.841	8.897	After annealing	8.799	8.849
er shock	8.850	8.922	After shock	8.805	8.842
er tempering	8.857	8.925	After annealing	8.823	8.866
er shock	8.870	8.939	After shock	8.832	*8.851
er tempering	8.871	8.937	After annealing	8.845	8.856
er shock	8.877	8.948	After shock	8.836	8.841
er tempering	8.880	8.944	After annealing	8.850	8.829
er shock	8.888	8.955	After shock	*8.840	*8.824
er tempering	8.887	8.951	After annealing	8.882	8.845
er shock	8.898	8.952	After shock	§8.854	8.836
er tempering	8.906	8.952	Gain in density	0.072	0.044
density increased om	0.102	0.177			

*Cracks. †Cracks. The fins are filed off. ‡Crack on the edge. §Breaks.

The prominent fact which is shown by these numbers is that the den- is increased by mechanical action, tempering, and annealing, in a narkable degree.

The increase is greatest in the tempered specimens.

t should be remembered that but limited confidence can be placed in figures obtained for the annealed metal, because it cracks and splits the edges, while it does not alter at all when it has been tempered.

As it is stated in books that tempering has the effect of diminishing the density of this bronze,* I examined this point very carefully, and made many other experiments, varying the composition (from 18 to 22 per cent. of tin), the form, and the weight of the specimens. All are concordant, as is shown by the following table:

TABLE 9.

	Density.			
	I.	II.	III.	IV.
Bronze melted	8.872	8.682	8.822	8.337
Bronze tempered	8.907	8.723	8.836	8.543
Bronze hammered	8.915	8.843	8.895	8.771
Bronze tempered	8.928	8.842	8.904	8.777
Bronze hammered	8.938	8.909	8.923	8.871
Bronze tempered	8.947	8.910	8.930	8.877
Bronze hammered	.....	8.932	.....	8.918
Bronze tempered	.....	.....	.....	8.922
Bronze hammered	.....	.....	.....	8.937
Bronze tempered	.....	.....	.....	8.943
Bronze hammered	.....	.....	.....	8.944
Increase of density	0.075	0.250	0.108	0.417

The thickness was reduced in these experiments from seventeen to seven millimeters.

When this bronze is cooled slowly the experiments are less convincing, because the metal breaks, or at least cracks easily, under shock. However, as my first object in undertaking this work was to clear up these obscure phenomena of tempering, and as I count for thus clearing them up upon the variations of density, I made numerous experiments, in some compressing the material slightly, and in others preserving it from sudden shock by an intervening body.

I give here some of the results:

TABLE 10.

	Density.	
	I.	II.
After casting	8.660	8.695
After slow cooling	8.653	8.689
After compression	8.738	8.750
After slow cooling	8.790	8.793
After compression	8.833	8.831

Thus there is always an increase in density whether the bronzes rich in tin be tempered or slowly cooled after compression.

These experiments confirm most clearly the fact affirmed by D'Arcet, that tempering softens the bronzes rich in tin, for we can flatten in the press the tempered bronzes, while it is only exceptionally, or by taking

*Dussaussoy, *Annales de Chimie et de Physique*, t. v, p. 228, we read:

Alloy of copper 80 and of tin 20.

	Non-tempered.	Tempered.	Tempered and softened.	Heated and cooled slowly.
Density	8.670	8.520	8.611	8.669

special precautions, that we are able to subject them to the same mechanical action without breaking them when they have been heated and cooled slowly.

This fact, being the inverse of that which is observed with steel, led me to examine the nature of the variations which the density of steel undergoes when placed under the conditions described.

3. *Action of tempering and annealing on steel.*

Reaumur and Rimmann admitted that the volume of tempered steel is greater by $\frac{1}{48}$ than that of steel which has not been tempered. Karsten, without absolutely contesting this opinion, does not consider it clearly demonstrated that steel diminishes in density by tempering. Colonel Caron, in his celebrated works on steel, has shown that tempering increases the volume of steel. Thus, after thirty successive temperings, the density which was 7.817 became 7.743,* and he concluded from his researches that the effect of tempering might be likened to the effect produced by the blow of a hammer on red-hot metal.

The steel experimented upon was of a very good quality used at the mint in Paris. The samples weighed from 130 to 150 grammes.

TABLE 11.

	Density.		
	I.	II.	III.
Bars forged	7.839	7.846	7.839
Bars forged, after tempering	7.735	7.749	7.738
Bars forged, after annealing	7.831	7.833	7.828
	IV.	V.	VI.
Bars forged	7.841	7.839	7.841
Bars forged, after annealing	7.843	7.845	7.843
Bars forged, after tempering	7.758	7.763	7.755

Thus tempering produces on steel forged or annealed an inverse effect to that which it produces on bronzes rich in tin; it diminishes its density instead of increasing it, from which it may be seen that tempering diminishes the density of annealed steel and makes it hard, while tempering increases the density of annealed bronze and makes it soft.

4. *Action of the press or of the roll, and of annealing, on steel.*

Two steel plates which had been used in the preceding experiments were employed.

TABLE 12.

	Density.	
	P=85^{kg}.830.	P=83^{kg}.465.
Forged steel	7.845	7.847
Forged steel, after one annealing	7.849	7.849
Forged steel, after one action of press	7.839	7.843
Forged steel, after second annealing	7.844	7.843
Forged steel, two impacts	7.838	7.839
Forged steel, three annealings	7.844	7.845
Forged steel, three impacts	7.837	7.841
Forged steel, four annealings	7.849	7.854
Forged steel, four impacts	7.849	7.849
Forged steel, five annealings	7.844	7.845

* *Comptes Rendus des Séances de l'Académie des Sciences*, January 5, 1873.

As the variations in density recapitulated in the preceding table are very slight, I tried to render them greater by passing small bars of well-annealed steel under a steel roll. The following table shows that if the results are in the same direction they are no more pronounced, and the experiment is very soon terminated by the breaking of the metal.

TABLE 13.

	Density.	
	P=77c.242.	P=76c.595.
Steel annealed	7.832	7.833
Steel rolled	7.827	7.824
Steel annealed	7.829	7.830
Steel rolled	7.822	7.820
Steel annealed	7.826	7.827
Steel rolled	7.816	7.822

The differences that bronze and steel present when alternately annealed and tempered are again encountered here, but in a less degree. While the mechanical action increases the density of the annealed bronze, it very slightly but still sensibly diminishes the density of annealed steel, and, on the whole, tempering and shock increase the density of annealed bronze, while they diminish the density of annealed steel.

But the variations are very decided for bronze and very slight for steel.

5. *Bronzes rich in tin.*

Examining Table 12 we see that the density is by annealing brought back to what it was before the action of the press; after five annealings and four powerful blows of the press, there was no sensible variation, and consequently we see how a block of annealed steel submitted to compression in making coin, sustains twenty, thirty, and even many more annealings and shocks, without any apparent difference in its work. Annealing restores the metal to the condition in which it was before the mechanical treatment.

Immediately following the researches published by D'Arcet in 1814* on the softening of the bronzes by tempering, experiments were made in different places, and particularly at *l'École des Arts et Metiers* at Châlons, on the tamtams and cymbals, instruments that we did not then manufacture and do not now in European countries, but which we obtain from China or from Turkey in Asia, and M. Maillard, head of the foundery of the "École" at Châlons, succeeded in making some of a tempered alloy containing

Copper	80.5	100.
Tin	19.5	

It was thought that this process was the same as that employed by the Orientals, and this opinion is to-day generally accepted among chemists.

Afterwards, St. Julien advanced the opinion that the Chinese worked the bronze red hot,† but D'Arcet held that St. Julien had been led into error,‡ because bronze greatly increases in density when heated, while the density of the Chinese instruments is very much less than that of heated bronze, and further, this bronze can be pulverized at red heat.

* D'Arcet, *Bulletin de la Societé d'Encouragement*, p. 289, 1814.
† St. Julien, *Annales de Chim. et de Phys.*, t. liv, p. 329, 1833.
‡ D'Arcet, *Annales de Chim. et de Phys.*, t. liv, p. 331, 1833.

In view of this contradictory testimony, I consulted the best instrument-makers of Paris, MM. Gautrot and Lecomte, who assured me that working this bronze cold is impracticable industrially, even after tempering, and I knew, on the other hand, that M. Maillard had encountered great difficulties in making these instruments, as great numbers of them were broken in the course of the work, and they are all thicker than the Chinese instruments.

I analyzed at that time fragments of the real Chinese instruments, and I found

Tin in 100 parts.
22.80
21.20
20.80
19.67

I ascertained the density of two good-sized specimens. It was—

For one	8.909
For the other	8.948

I submitted to cherry-red heat some bronze containing 20 per cent. of tin, and I found, as D'Arcet had shown, that this metal is reduced to powder by blows. I then sought to ascertain if this metal would not, like zinc, be malleable at the intermediate temperatures. About 100 to 200 degrees it is brittle as when cold or at a cherry-red heat, but at dark-red, and a little under that temperature, it can be forged as easily as iron or aluminium bronze. At these temperatures it flattens without breaking under the heaviest blows of the hammer; it is so easily flattened that it can, in some cases, be reduced from a thickness of 14 millimeters to that of 1 to 2 millimeters, and if the temperature be raised a little it becomes so soft that it can be wound upon itself by subjecting it repeatedly to slight shocks. In a word, the work is thus done with greater accuracy and rapidity, and becomes, industrially speaking, practicable.

It remains to be considered whether the density approaches to that which is obtained by cold hammering and to that of the Chinese metal.

With this object the two tempered specimens which formed the subject of Table 8 were heated red-hot, and the following results obtained:

TABLE 14.

	Density.	
	I.	II.
Metal tempered	8.906	8.952
Metal hammered at red heat, diminishing its weight one-quarter	8.953	8.942
Metal tempered anew	8.958	8.924
Metal hammered again more gently on account of its brittleness	8.939	8.924
Metal tempered again	8.933	8.924
Metal hammered gently	8.920	8.924

The metal having been cold-beaten for a long time, I repeated these operations at a higher temperature with new metal.

TABLE 15.

	Density.
Cast metal	8.764
Cast metal after first hammering at dark-red heat	8.893
Cast metal after second hammering at dark-red heat	8.941
Metal after third hammering at dark-red heat	8.948
Metal after fourth hammering at dark-red heat	8.943
Metal after fifth hammering at dark-red heat	8.927

The thickness was reduced from six millimeters to one.

The same experiments at high temperature were repeated on the metals containing from 18.5 to 21.5 of tin, when they had been cast at a very high temperature.

TABLE 16.

	Density.
Bronze at 18.5 per cent. tin, after casting at a high temperature	8.882
The same after prolonged hammering at dark-red heat	8.933
Bronze at 20 per cent. tin, after casting at a high temperature	8.912
The same after prolonged hammering at dark-red heat	8.920
Bronze at 21.5 per cent. tin, after casting at a very high temperature	8.938
The same after prolonged hammering at dark-red heat	8.929
Bronze at 20 per cent. tin, rolled at red heat	8.819 8.837 8.865 8.873

The thickness was reduced from 6 millimeters to 1.

Two facts follow from these experiments:

1st. Working hot does not increase the density more than working at low temperature.

2d. The metal attains this density very rapidly by the working hot, and without danger of rupture; while cold the action is extremely slight and very difficult.

If I add that the Chinese tamtams bear traces of numerous hammerings, which indicate that the metal was worked when it was softened by heat, it will, I think, be admitted, as I stated when I published these results,* that the working cold is not carried on in China as D'Arcet supposed, and that the method of fabrication attempted at *l'École des Arts et Metiers* at Châlons is not the method practiced in the East, but that the metal is worked there *hot*, as St. Julien declared.

Had there remained any uncertainty it would have been removed when, some days after the publication of these researches, MM. St. Julien and Champion published on their side a work in which M. Champion stated that he had seen this work in China, and that the metal was heated.†

M. Champion and myself unite to introduce this desideratum into the industrial arts of European countries, and we have succeeded in making, at the works of MM. Cailar and Guin, two tamtams, which have the external characteristics and the sonorousness of the Chinese instruments. But we utilized the facility with which I had observed this bronze to flatten to shorten the operation and to diminish hand labor, by first subjecting the cast alloy, very thick and red hot, to the action of the rolling-mill, which machinery, according to M. Champion, is unknown to the Chinese, and which, in every case, he ascertained by observation was not employed by them in reducing bronze for the manufacture of sonorous instruments.

§ V. BRONZES LESS RICH IN TIN APPROACHING CANNON-BRONZE IN THEIR COMPOSITION.

Cu =	94 to 88
Sn =	6 to 12
	100

The bronzes were submitted to the same operations as the preceding.

1. *Tempered and annealed alternately.*

* *Comptes Rendus des Séances de l'Académie des Sciences*, t. lxix, p. 343.

† *Industries anciennes et modernes de l'Empire Chinois*, Lacroix, 1869.

TABLE 17.

Alloy of 88 Cu } 100
12 Sn }

Density, P = 47lbs. 806.

empering	8. 625
nnealing	8. 632
empering	8. 624
nnealing	8. 635
empering	8. 632

TABLE 18.

Gun-bronze, at 90 Cu } 100
10 Sn }

	Density.			
	I. P=69lbs.686.	II. P=70lbs.902.	III. P=112lbs.468.	IV. P=104lbs.783.
sting	8. 564	8. 677	8. 684	8. 491
mpering	8. 516	8. 635	8. 657	8. 498
nealing	8. 528	8. 643	8. 670	8. 431
mpering	8. 532	8. 645	8. 671	8. 437
nealing	8. 536	8. 648	8. 674	8. 434
mpering	8. 529	8. 648	8. 673	8. 436
nealing	8. 526	9. 643	8. 676	8. 436
mpering	8. 526	8. 626	8. 664	8. 436

	Density.	
	P = 69lbs.198.	P = 112lbs.590.
sting	8. 541	8. 705
nealing	8. 491	8. 689
mpering	8. 495	8. 684
nealing	8. 504	8. 692
mpering	8. 505	8. 693
nealing	8. 479	8. 651
mpering		8. 661

TABLE 19.

Bronze at 94 Cu } 100
6 Sn }

Density, P = 141lbs. 830.

asting	8. 537
empering	8. 491
nnealing	8. 501
empering	8. 502
nnealing	8. 507
empering	8. 505

	Density.	
	II. P=152lbs.516.	III. P=76lbs.599.
sting	8. 519	
nealing	8. 492	8. 807
mpering	8. 491	8. 806
nealing	8. 496	8. 802
mpering	8. 495	8. 804
nealing	8. 496	8. 809

These numbers show that the bronzes containing but little tin, susceptible of being cold-hammered, or even flattened like gun-bronze, do not increase in density when tempered or annealed like the preceding.

2. *Annealed or tempered and rolled alternately.*

TABLE 20.

Bronze $\begin{matrix} 94\ Cu \\ 6\ Sn \end{matrix}\Big\} 100.$

	Density.	
	I. P = 123gr.130.	II. P = 65gr.590.
After casting	8.541	.....
After rolling	8.672	8.752
After tempering	8.643	8.761
After rolling	8.722	8.836
After tempering	8.694	8.833
After rolling	8.772	8.871
After tempering	8.770	8.872
After rolling	8.827	8.921
After tempering	8.824	8.926
After rolling	8.897	8.929
After tempering	9.907	8.936
After rolling	8.913	8.939
After tempering	8.919	8.739
After rolling	8.933	.....
The density increases from	0.392	0.181

	Density.	
	III. P = 127gr.920.	IV. P = 81gr.109.
After casting	8.541	.....
After rolling	8.669	8.773
After annealing	8.627	8.772
After rolling	8.722	8.836
After annealing	8.729	8.879
After rolling	8.801	8.874
After annealing	8.801	8.875
After rolling	8.851	8.913
After annealing	8.852	8.923
After rolling	8.904	8.928
After annealing	8.919	8.929
After rolling	8.922	8.931
After annealing	8.931	8.934
After rolling	8.935	.....
The density increases from	0.394	0.161

The metal was reduced from a thickness of ten millimeters to that of one.

Comparing these results with those given by the bronzes rich in tin, we find that tempering and annealing give about the same increase in density, while the increase was much greater for the tempered metal in the alloys rich in tin.

These alloys seemed to be as easily worked after annealing as after tempering.

An attempt was made to verify this last point by operating under practical conditions; that is to say, by reheating the metal in the air, working on bronze of 10 and bronze of 6 per cent. tin, which was in the form of strips four millimeters wide. The mechanical action and heat were the same; the only difference was in the cooling; while one speci-

men was tempered when red hot, the other was left out in the air. The results are given in the following table:

TABLE 21.

1. *Bronze at* 10 *per cent. tin.*

	Density. I. P=66°.928.
After 6 impacts of the press	8.887
After annealing	8.833
After 9 impacts of the press	8.905
After annealing	8.902
After 96 impacts (and 32 annealings)	8.930
After annealing	8.935

	Density. II. P= 66° 958.
After 6 impacts of the press	8.898
After tempering	8.894
After 9 impacts of the press	8.904
After tempering	8.897
After 96 impacts (32 temperings)	8.904
After tempering	8.905

2. *Bronze of* 6 *per cent. tin.*

	Density. III. P=66°.002.
After 6 impacts of the press	8.924
After annealing	8.923
After 9 impacts of press	8.936
After annealing	8.928
After 57 impacts (19 annealings)	8.931
After annealing	8.932

	Density. IV. P=65°.242
After 6 impacts of press	8.928
After tempering	8.924
After 9 impacts of press	8.929
After tempering	8.923
After 57 impacts (19 temperings)	8.934
After tempering	8.935

The tempering and the annealing take place in a similar manner, almost identically the same for bronze at 6 per cent. tin. Thus the density after 72 blows of the press, alternated with 24 annealings, increases from 8.924 to 8.932, and by tempering, from 8.928 to 8.935.

The workman observed no differences in the hardness of the metal annealed or tempered, and the ease of working secured was the same.

Two sheets of these bronzes were prepared, of a thickness of 15 millimeters, and these were subjected to the ordinary operations of coining after they had been cut in two, care being taken to have one of these parts annealed and the other tempered. When they had been reduced to strips 5 centimes in width, that is to say, 1 millimeter, the strips were cut and weighed.

TABLE 22.

1. *Bronze at* 10 *per cent. tin.*

	gr.
Weight of 15 strips after 3 temperings	76.90
Weight of 6 strips after 3 temperings	32.36
Weight of 10 strips after 3 temperings	53.50
Weight of 15 strips after 3 annealings	77.27
Weight of 6 strips after 3 annealings	32.07
Weight of 10 strips after 3 annealings	54.70

2. *Bronze at 6 per cent. tin.*

	gr.
Weight of 15 strips after 3 temperings	73.82
Weight of 6 strips after 3 temperings	32.14
Weight of 10 strips after 3 temperings	48.95
Weight of 15 strips after 3 annealings	73.98
Weight of 6 strips after 3 annealings	31.49
Weight of 10 strips after 3 annealings	51.00

No difference was observed in working the alloys whether annealed or tempered, and the weight of the annealed strips did not differ materially from that of the tempered ones.

The director of the mint at Paris, M. Bijon, to whom I also owe many thanks for all the facilities he procured for me in the prosecution of these researches, assured me that no differences had been observed in the working until at one time, work not being very urgent, the plates were left to cool in the air instead of being tempered in water. It is preferable to cool the bronze rapidly in order to diminish its oxydization, and especially to detach the scales of oxide which form during the reheating, and which have the double inconvenience of soiling the rolls and of injuring the plates.

3. *Liquation in gun-bronzes.*

Liquation is not so considerable as is generally supposed. The following table recapitulates some of the numerous analyses which were made of cannon during the siege of Paris, with my colleague, M. Desmarais, at M. Thiébault's, and at Cailar & Guin's:

In table 24 will be found the analysis made by M. Drouin and myself on the different parts of the cannon cast at the *École des Arts et Metiers* of Angers, for which I am indebted to the courtesy of M. Soux, chief of the mill-wright shop of this establishment.

TABLE 23.

Samples taken.	Sn.	Zn.	Pb.	Cu.*
INTERIOR.				
No. 1.				
At the breech	8.72	1.80	0.92	88.56
At top of trunnion	7.18	2.00	0.74	90.08
Toward the muzzle	7.08	1.60	0.83	90.49
No. 2.				
At the breech	9.85	2.40	1.86	85.89
At the trunnion	9.44	2.20	1.86	86.50
Toward the muzzle	8.84	2.40	1.86	86.90
No. 3.				
At the breech	9.44	0.93	0.90	88.43
At the trunnion	9.74	1.11	0.60	88.55
Toward the muzzle	8.98	0.93	0.85	89.24
EXTERIOR.				
No. 1.				
At the breech	8.74	2.00	0.83	88.43
At top of trunnion	8.72	2.00	0.93	88.35
Toward the muzzle	7.70	1.60	0.83	89.87
No. 2.				
At the breech	9.96	1.80	1.86	86.38
At the trunnion	9.85	2.40	1.86	85.89
Toward the muzzle	9.66	2.40	1.86	86.08
No. 3.				
At the breech	9.93	1.21	0.80	88.06
At the trunnion	8.72	1.11	1.00	89.17
Toward the muzzle	8.92	1.21	0.80	89.07

* Determined by difference.—*Ann. de Chim. et de Phys.*, 4 série, t. xxx, 1873, 25.

TABLE 24.

	m.
Length of the cannon with its sinking head	2,512
Length of the sinking head	1,500

The inner shavings were taken from a cylinder of 65 millimeters diameter having the same axis as the cannon. They were thoroughly washed in ether.

INTERIOR.

Distance from the breech.	Sn.	Pb.*	Zn.	Cu.†
M.				
0.40	8.965	0.165	1.600	89.270
0.60	9.014	0.165	2.600	88.821
0.80	9.014	0.165	2.200	88.621
1.00	8.726	0.165	1.200	89.909
1.20	9.046	0.165	0.800	89.989
1.40	8.732	0.165	1.200	89.903
1.60	8.762	0.165	0.600	90.473
1.80	8.999	0.165	0.800	90.036
Mouth.	8.762	0.165	2.100	88.973

Average of tin in the interior, 8.907.

EXTERIOR.

0.40	9.662	0.165	1.600	88.573
0.60	9.282	0.165	1.600	88.953
0.80	9.454	0.165	2.000	88.381
1.00	9.676	0.165	1.200	88.959
1.20	9.581	0.165	0.800	89.454
1.40	9.550	0.165	1.400	88.885
1.60	9.314	0.165	2.000	88.521
1.80	9.534	0.165	1.000	89.301
Sinking head at 0m.65 from the muzzle, 9.344		0.165	0.100	90.391

Average of tin at the exterior, 9.507.

* Average of total lead found in the different parts. † Determined by difference.

The part of the cannon which is in the axis of the piece, and which is cut away by the drill, is not homogeneous, especially toward the breech. Crystalline particles of gray tint were found there, which being separated as carefully as possible gave upon analysis:

Tin	12.30	11.21	13.89	14.49
Zinc	3.20	5.40	6.40	14.49

It does not follow that the central parts are richer in tin. On the contrary it has been shown by experiment that the exterior is richer in tin than the interior. This last fact, which clearly follows from the preceding tables, had been previously stated by Colonel Dussanssoy, contrary to the opinion previously held at cannon founderies.

The following table does not indicate that the sinking head may have the effect of increasing the density of the piece as has also been supposed.

TABLE 25.

Distance from the breech.	Quantity of tin, per cent.	Density.	Distance from the breech.	Quantity of tin, per cent.	Density.
0.20	10.498	8.472	1.20	9.291	8.618
0.40	9.065	8.539	1.40	9.048	8.549
0.60	9.140	8.539	1.60	8.969	8.500
0.80	8.752	8.549	1.80	8.526	8.458
1.00	9.039	8.460	2.00	8.530	8.374

4. *Manufacture of medals.*

Analysis of antique medals shows that though the ancients sometimes used copper for this purpose, they ordinarily employed bronze in which the proportion of tin varied between large limits (from 1 to 25 per cent.). The manufacture of medals with a bronze rich in tin is not possible at the present day on account of its hardness, and because considerable relief is necessary, while it was very slight in the medals of antiquity. Bronze has been wholly given up in our own country and copper substituted for it, but copper also presents some serious inconveniences. It rusts badly, has no ring, its red tint is not artistic, and this is concealed by an artificial bronzing which adheres poorly, and which causes different medals to vary in tone.

In 1828 M. de Puymaurin made a large number of experiments and continued them until 1832, after which an alloy of 94 copper, 4 tin, and 2 zinc was adopted, of which from time to time medals were manufactured until 1847, at which time it was entirely given up on account of the hardness of the metal leading to a deterioration of the coin. The hardness of bronze increases in fact very rapidly with the proportion of tin, and the following is the average of many experiments with the apparatus described above:

	Impacts necessary in order to obtain a depression of—	
	4mm.	1mm.
Copper	19	7
Bronze, with 97 parts copper	23	8 to 9
Bronze, with 96 parts copper	27	10
Bronze, with 95 parts copper	38	14
Bronze, with 94 parts copper	40	15
Bronze, with 90 parts copper	Did not succeed with 70 blows.	

After these experiments various medals were struck at the mint in Paris, with different alloys in the ordinary working conditions. The differences, which are unimportant for medals less than 35 millimeters, become more noticeable when the dimensions attain to 50 millimeters. There were necessary in this latter case—

With pure copper	7 compressions.
With bronze with 97 parts copper	10 compressions.
With bronze with 96.5 parts copper	12 compressions.
With bronze with 96 parts copper	13 to 14 compressions.
With bronze with 95 parts copper	16 to 17 compressions.
Alloy of 95 copper, 4 tin, 1 zinc	14 compressions.
Alloy of 94 copper, 4 tin, 2 zinc	16 to 18 compressions.

From which I conclude that bronze of 96 and 97 parts copper may be employed to great advantage and with no serious inconvenience in the manufacture of medals. Its hardness, much less than that of the alloy of M. de Puymaurin, does not much exceed that of copper; it possesses a certain sonority and casts well, rolls evenly, and its color is more artistic than that of copper.

The action of the press and of heat modifies its density but little.

TABLE 26.

Density.	Medal of 68mm, in bronze, with 4 per cent. tin.	Medal of 68mm, in alloy of Cu 94, Sn 4, Zn 2.
first annealing	8.926	8.901
first stroke	8.944	8.909
second annealing	8.940	8.912
second stroke	8.941	8.916
third annealing	8.939	8.910
third stroke	8.946	8.916
fourth annealing	8.943	8.911
fourth stroke	8.947	8.915
fifth annealing	8.940	8.912

VI. PURE COPPER, ITS PERMEABILITY TO LIQUIDS.

Copper alloyed with iron.

ither pure copper which had been used in the preceding experiments ery fine copper in plates, such as is used in the mint at Paris for king medals, was employed.

Tempered and annealed alternately.

TABLE 27.

	Density.			Density.	
	I. P=101gr.561.	II. P=100gr.892		III. P=102gr.987.	IV. P=102gr.104.
er rolled	8.921	8.923	Copper rolled	8.915	8.919
er annealed	8.888	8.891	Copper tempered	8.908	8.911
er tempered	8.868	8.856	Copper annealed	8.858	8.865
er annealed	8.852	8.853	Copper tempered	8.834	8.840
er tempered	8.828	8.831	Copper annealed	8.833	8.840
er annealed	8.812	8.809	Copper tempered	8.806	8.819
er tempered	8.788	8.785	Copper annealed	8.797	8.810
er annealed	8.781	8.783	Copper tempered	8.773	8.785
nution of density	0.140	0.140	Diminution	0.142	0.134

Annealed or tempered and rolled alternately.

TABLE 28.

	Density. I. P=79gr.835.
per rolled	8.877
per annealed	8.767 to 8.770
per rolled	8.831
per annealed	8.751 to 8.756
per rolled	8.825
per annealed	8.758
per rolled	8.868
per annealed	8.744 to 8.755

	Density. II. P=79gr.765.
per rolled	8.874
per tempered	8.786 to 8.791
per rolled	8.841
per tempered	8.816
per rolled	8.850
per tempered	8.839
per rolled	8.876
per tempered	8.849

These experiments show that heat considerably lessens the density of copper, for even after repeated rolling which reduced the thickness of the sheet from 9 millimeters to $1^{mm}.5$, the density diminished greatly.

3. *Porosity of copper; its permeability to liquids.*

It will be noticed that in the preceding table, the density after annealing and tempering was represented by several different numbers. The copper gains in weight by remaining even for a little while in water, when it has been heated either in the midst of coal dross, or in the empty box surrounded by coal dross.

Every one who has worked or handled copper has noticed that it almost always contains little cavities, and founders know that it is very difficult to obtain a really sound casting of this metal.

Marchand and Scheerer attribute this to the oxygen contained in the copper, which is disengaged at the moment of solidification by a phenomenon analogous to that which produces the spitting of silver.

Permeability is not due to this cause alone, for rolled copper which is not at all porous, becomes so when reheated in the midst of coal, or in a box surrounded with coal. It depends on various other causes, and especially on the fact that cast copper, even after it has been melted in the presence of carbon, contains a small quantity of oxide which has been produced by the action of the heat at the temperature for annealing.

TABLE 29.

	Weight of a bar of copper.	Immersed for 20 hours in benzine it absorbs from it—
	Gr.	*Gr.*
After the first annealing in a box surrounded with coal	73.692	0.027
After a second annealing in a box surrounded with coal	73.685	0.020
After a third annealing in a box surrounded with coal	73.681	0.012

This increase of weight is due to a simple absorption of the liquid into the metal, for it takes place with very different liquids, and the metal, by simply being exposed to the air, returns to its original weight.

TABLE 30.

	Gr.
Weight of a sample of copper	101.141
Weight of this sample after two days in water	101.168
Weight of this sample after two days in dry air	101.143
Weight of this sample after two days in benzine	101.155
Weight of this sample after two days in dry air	101.142
Weight of this sample after two days in water	101.160
Weight of this sample after two days in dry air	101.145
Weight of this sample after one annealing in coal	101.139
Weight of this sample of copper after two days in water	101.226
Weight of same after two days in dry air	101.144

The copper attained this porosity in rolling.

TABLE 31.

Copper melted, then cast at a low temperature.

	Gr.
Weight in the air	78.442
Weight after one day in water	78.509
Weight after one day in air	78.443
Weight after rolling	78.439
Weight after three days in benzine	78.439

Copper melted, then cast at a very high temperature, does not possess this permeability.

	Gr.
Weight of a sample of copper cast very hot	123.740
Weight of this sample of copper after three days in water	123.738

The density of this sample cast at a high temperature was 8.939, while the density of the sample cast at a low temperature—of the preceding table—was only 8.039. This explains the differences which may be found in the various works upon the density of melted copper. According to Marchand and Scheerer* these densities may vary from 7.720 to 8.921. We have just indicated a superior number to this last, 8.939. The lowest limit given above is never obtained in ordinary circumstances. Generally this density fluctuates between 8.0 and 8.81.

4. This porosity does not exist when the copper is reheated in the air, that is to say, in the ordinary conditions under which this metal is worked in the manufacture of medals.

TABLE 32.

	Density.	
	I. P = 87°.193.	II. P = 80°.077.
Copper rolled	8.920	8.903
Copper annealed	8.921	8.905
Copper tempered	8.924	8.906
Copper annealed	8.927	8.907
Copper tempered	8.926	8.899
Copper retempered	8.922	8.903
Copper annealed	8.930	8.903

	Density.	
	III. P = 88°.637.	IV. P = 79°.049.
Copper rolled	8.921	8.919
Copper tempered	8.922	8.921
Copper annealed	8.924	8.923
Copper tempered	8.923	8.921
Copper annealed	8.922	8.922
Copper annealed anew	8.927	8.922
Copper tempered	8.926	8.920

While annealing and tempering considerably lessen the density of copper when not exposed to the air during the operations (Table 27), these same processes do not materially modify the condition of this metal when it is exposed to the air while working it.

Mechanical action and action of heat alternately, on copper heated while exposed to the air.

* Percy, *Metallurgie*, t. v, p. 67.

TABLE 33.

	Density.	
	I. P=80^{kg}.930.	II. P=81^{kg}.044.
Copper rolled	8.916	8.919
Copper tempered	8.925	8.926
Copper rolled	8.920	8.920
Copper tempered	8.922	8.919
Copper rolled	8.911	8.909
Copper tempered	8.915	8.912
Copper rolled	8.912	8.913
Copper tempered	8.913	8.915
Copper rolled	8.912	8.913
Copper tempered	8.913	8.914
Diminution of density	0.003	0.005

	Density.	
	III. P=80^{kg}.672.	IV. P=81^{kg}.038.
Copper rolled	8.923	8.921
Copper annealed	8.925	8.922
Copper rolled	8.913	8.889
Copper annealed	8.910	8.910
Copper rolled	8.902	8.899
Copper annealed	8.902	8.896
Copper rolled	8.890	8.889
Copper annealed	8.900	8.902
Copper rolled	8.894	8.887
Copper annealed	8.896	8.901
Diminution of density	0.037	0.022

These plates were reduced from a thickness of 9 millimeters to that of 1 millimeter under the same conditions. Comparing these results with those of Table 28, which contains the results obtained when the copper was not exposed to the air while heating, a complete contrast was shown. While annealing and tempering increased the density in the first case, they diminished it in the second.

Another very striking fact when the piece is exposed to the air is, that the increase of density resulting from the heat is very nearly compensated by the tempering, so that the plate, after being made considerably thinner, is found to have the same density as before the operation. By annealing, the uniformity becomes less, and the density materially diminishes. I struck a copper medal at the workshop of the mint, the metal being exposed to the air during the reheating, and the results were as follows:

TABLE 34.

Copper medal in strong relief.

	Density, P=40^{kg}.430
Strip rolled	8.909
Strip after the first pass	8.918
Strip after the first tempering	8.918
Strip after the second pass	8.915
Strip after the second tempering	8.916
Strip after the third pass	8.908
Strip after the third tempering	8.912

On the whole, copper exposed to the air during heating, tempered and then struck in the press, shows the same effects as steel annealed and struck. (Table 8.)

The density of both diminishes when they are subjected to mechanical action. Heat restores them sensibly to their original volume, so that we can see how they may be practically employed with advantage in making coins and medals.

The opposite results given by copper exposed to the air during heating and protected from the air (Tables 28 and 33), exhibit the contradictory effects of the experiments of O'Neil and of Marchand and Scheerer,* in which the former obtained a diminution of density by compression, while the others showed a sensible increase.

Copper, in these annealings in the air, oxidizes strongly. In fact the four samples which were the subject of Table 32, were heated red hot in the midst of coal dust twice in the course of four or five hours.

Their weights which were—

gr.	gr.	Oxygen determined.
No. 1, 76.100, became	75.977	0.123
No. 2, 69.537, became	69.488	0.049
No. 3, 75.851, became	75.760	0.091
No. 4, 68.078, became	68.025	0.053

And this quantity of oxygen is a minimum. The metal after this reduction became again permeable to liquids.

5. The addition to copper of small quantities of foreign matter, iron, for example, increases the porosity, as do small quantities of oxygen. The copper acquires tenacity and elasticity by this adjunction of iron, while retaining a certain malleability.

The question has often been raised as to whether copper allies itself to iron. I give here the results of my experiments on this point.

1st. We heated in a temperature sufficient to melt cast iron—

Copper	90
Cast iron	10

The ingot obtained contained, at its highest part, iron uncombined.

2d. We heated very hot and held some time in fusion—

Copper	90
Rivets	10

The ingot obtained furnished upon analysis—

Top	1,600 iron.
Bottom	365 iron.

3d. We heated very hot and kept melted some time—

Copper	96
Rivets	6

The metal appeared very homogeneous. Its density, taken at two different points, gave—

8.881
8.876

The matter is easily forged, stretches and coils upon itself. It rolls with such facility that *without annealing* a bar of it can be reduced from a thickness of 9 millimeters to that of 1 millimeter. Its tenacity exceeds that of copper.

Examining with a magnifying-glass the plates 1 millimeter in thickness mentioned above, gray spots may be seen at certain points, but analysis of these points shows no material difference between them and other portions. There was found—

Iron	5.383	5.285	5.236

This substance made very hot in the crucible gives a button in which there remains only—

Iron	0.167 per cent.

* Percy, *Metallurgie*, t. v, pp. 69 and 72.

4th. These two metals were alloyed in variable proportions, melted in earthen tubes 15 centimeters in length, and after being kept three hours in fusion, were left to cool slowly.

	Iron, per cent.		
	Top of bar.	Bottom of bar.	Density.
1	12.693	4.545	8.839 to 8.771
2	9.290	3.690	
3	6.876	3.692	
4	4.619	4.590	
5	4.226	4.288	8.88
6	2.950	2.660	

The length of the ingot was from 6 to 8 centimeters. The metal containing 4.5 per cent. of iron appearing homogeneous, some experiments were made upon it comparable to those which were made on copper.

TABLE 35.

	Density. I. P = 29".402.
Melted metal	8.879
Metal after tempering	8.874
Metal after rolling	8.884
Metal after tempering	8.878
Metal after rolling	8.887
Metal after tempering	8.884
Metal after rolling	8.888
Metal after tempering	8.889

	Density. II. P = 29".461.
Metal after rolling	8.891
Metal after annealing	8.892
Metal after rolling	8.894
Metal after annealing	8.894
Metal after rolling	8.896
Metal after annealing	8.894

Ferrous copper acts, then, like copper exposed to the air during reheating, or like steel. The action of heat alternating with the rolling restores it evidently to the same volume.

The ferruginous copper is not permeable to liquids. This metal is not, however, a homogeneous alloy, for after being reheated at a very high temperature for three hours and a half, the solidified ingot gave upon analysis—

	Top.	Bottom.
Iron, per cent	6.50	4.00

However, as it had shown a tenacity incomparably greater than that of copper, the following experiments were made with a view to determining the mechanical properties :

TABLE 36.

Elongations in millimeters corresponding to loads in kilograms.

	Name of Metals.	P. ct.	Area, sq. mm.	800	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700
1	Copper of commerce, melted	....	94	0	1	3	5	(*)	.....	.....	.....	.....
2	Copper of commerce, rolled	....	93	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
3	Pure copper, melted	....	111	1.25	3.0	4.5	5.5	6.0	.....	.....	.....	.....
4	Pure copper, melted	....	98	2.5	5.0	(†)	.....	.....	.....	.....	.....	.....
5	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.75	1.5	2.5	(‡)	.....
6	Copper and iron, melted	2	92	0.25	0.25	0.25	0.25	0.50	2.0	3.0	3.5	3.5
7	Copper and iron, melted	4.5	97	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	Copper and iron, melted	4.5	97	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	Pure copper, rolled	....	81.5	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	Pure copper, rolled	....	89	.....	.....	.....	.....	.....	.....	.....	.....	——
11	Copper and iron, rolled	4.5	88	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	Copper and iron, rolled	4.5	90	.....	.....	.....	.....	.....	.....	.....	.....	.....

	Name of Metals.	P. ct.	Area, sq. mm.	1,800	1,900	2,000	2,100	2,200	2,300	2,400	2,500	2,600	2,700	2,800
1	Copper of commerce, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	Copper of commerce, rolled	....	.....	0.5	0.5	1.5	2.5	4.5	5.5	.....	.....	.....	.....	.....
3	Pure copper, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	Pure copper, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	Copper and iron, melted	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	Copper and iron, melted	2	.....	4.5	5.5	7.0	8.5	10.0	12.5	15.0	.....	.....	.....	.....
7	Copper and iron, melted	4.5	.....	.....	0.25	2.5	(§)	.....	.....	.....	.....	.....	.....	.....
8	Copper and iron, melted	4.5	.....	.....	.....	.....	.....	.....	0.25	1.0	1.20	1.75	2.5	4.0
9	Pure copper, rolled	....	.....	0.25	0.25	2.0	4.0	8.75	12.0	.....	.....	.....	.....	.....
10	Pure copper, rolled	....	.....	0.5	1.5	3.0	4.5	8.0	16.00	.....	.....	.....	.....	.....
11	Copper and iron, rolled	4.5	.....	.....	——	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	Copper and iron, rolled	4.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

	Name of Metals.	P. ct.	Area, sq. mm.	2,900	3,000	3,100	3,200	3,300	3,400	3,500	3,600	Breaking load.	Strength per sq. mm.	Density.
												Kilog.	*Kilog.*	
1	Copper of commerce, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	Copper of commerce, rolled	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,300‖	24.210‖	.....
3	Pure copper, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,300	11.711	8.039
4	Pure copper, melted	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,000	10.204	.....
5	Copper and iron, melted	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	Copper and iron, melted	2	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,400	26.086	.....
7	Copper and iron, melted	4.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	Copper and iron, melted	4.5	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,800	28.865	8.879
9	Pure copper, rolled	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,300	28.220	8.904
10	Pure copper, rolled	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2,300	25.842	.....
11	Copper and iron, rolled	4.5	.....	0.25	0.5	0.5	1.0	2.5	2.5	4.75	.....	3,500	39.772	8.891
12	Copper and iron, rolled	4.5	.....	.....	.....	.....	0.25	0.75	1.5	3.5	9.0	3,600	40.000	.....

* The assay was arrested because a blowhole was formed in the sample.
† The broken section presents blowholes.
‡ At 1,600 kilograms one lug of the piece was broken.
§ The sample broke without the two pieces being entirely separated.
(*Ann. de Chim. et de Phys.*, 4 *série*, *t.* XXX, Nov., 1873, 26.)

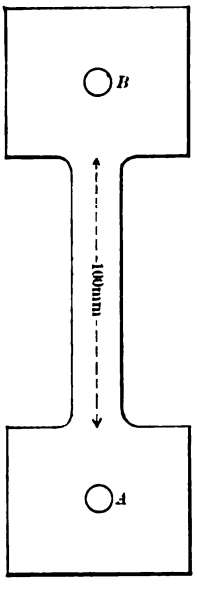
OBSERVATION.—The melted copper (Nos. 1, 3, 4) contains blowholes which destroy its tenacity. It elongates under light loads, and breaks, also, under a small load. The copper acquires a certain tenacity by rolling. While the resistance of melted copper is from 10 to 12 kilograms per square millimeter, that of the same copper attains, by rolling, 25 to 28 kilograms. The ductility is less, and the elongation becomes no longer evident under loads of 1,800 kilograms.

The introduction of iron into the copper leads to great changes in the mechanical properties of the metal:

1st. If the metal has been simply melted, it retains its ductility and elongates under light loads, especially when the quantity of iron exceeds 2 per cent. Its resistance attains to that of copper which, by rolling, has been reduced to half its thickness.

2d. If the metal has been rolled its ductility is small, but it presents a considerable resistance of 39 to 40 kilograms per square millimeter.

These experiments were made on bars of 2 kilograms weight prepared and cast with care, then cut and worked so as to give them the following form:



In order to determine the resistance, this piece was firmly fastened to the building by an iron fork fitted to A. Another fork placed in B was fixed to a bar forming a lever, at the other end of which was placed a table on which were the weights. The experiments were made at the works of Graffenstaden under the direction of M. Brauer.

This great strength of copper containing iron should not be attributed to the density of the material, for the alloyed copper which presented the greatest resistance had a density of 8.891; that is to say, less than that of pure rolled copper, which was 8.904.

With the exception of the metal bearing the numbers 1 and 2, all these samples were melted with the same copper, rolled to the same point by the same workman, and, in short, treated in precisely the same way.

The hardness of copper melted, rolled, and alloyed with iron presents differences of the same sort. We give here the results which were obtained with the Magna apparatus.

Depth of the impressions produced by the same blow:

	Mm.
Copper melted	2.50
Copper rolled	1.50
Copper alloyed with 3 per cent. of cast iron	1.10
Copper alloyed with 3 per cent. of rolled iron	0.90

Upon the whole, the introduction of trifling quantities of iron into the copper destroys its great softness and porosity, and considerably increases its tenacity and hardness, without destroying its malleability.

M. Bobierre, in order to obtain some idea of the resistance of different metals to corrosion, plunged some into water containing alum, salt, and cream of tartar. I placed in this liquid two plates of equal dimensions, one of pure copper, the other of copper alloyed with 2 per cent. of iron. The copper plate was affected more quickly than the other, and especially was the portion of copper dissolved very strong.

The liquor obtained with ferrous copper is green instead of blue.

At the end of five days, in operating upon two plates of the same size, weighing about 15 grammes, the plate of copper was found to have lost three decigrams more than the plate of ferrous copper.

§ VII. ALLOYS OF COPPER AND ZINC.

The zinc which I used had been purified by two distillations in the laboratory of the "*Société de la Vieille Montagne*," which generously placed it at my disposal.

I undertook the study of the various physical properties of these bodies, as I did of the alloys of copper and tin, but I was obliged to give up the examination of the fusibility and liquation, because the place where I had specially prepared for this work at the mint was not left at my disposal.

I have nothing special to say on the subject of their hardness; it in-

creases from the alloy 90 of copper to that which contains equal weights of copper and of zinc, Zn Cu.

The alloy $Zn^3 Cu^2$ and the alloy $Zn^2 Cu$ are extremely fragile and break at the first shock of the apparatus described before, and the others, containing more zinc, crack after a few blows.

The density was determined, first, of some ingots weighing from 60 to 100 grammes, then, on account of the greatly differing texture of these alloys, filings of them were operated upon with the greatest possible care. But it is difficult even by a sustained vacuum to eliminate all the bubbles of air, and I was afraid to heat the filings several times in water in order to secure the expulsion of the air, because water is attacked by zinc and the alloys rich in this metal; and, lastly, the volatility of zinc makes it difficult to prepare the alloys in exactly atomic proportions.

I give here, with these reservations, the results obtained:

TABLE 37.

Formula of the alloy.	Centesimal composition.	Actual composition.	Experimental density powder.		Ingots.	Calculated density.		Depth of the impression obtained by the same shock in the Magna apparatus.
				Average.				
$Zn^8 Cu$...	Zn 89.18 Cu 10.82	89.90	7.383–7.248	7.315	7.299	7.351	Material gray, like zinc	1.75mm.
$Zn^4 Cu$...	Zn 80.48 Cu 19.52	79.30	7.920–7.807	7.863	7.215	7.478	Material gray, like fibrous.	Breaks.
$Zn^2 Cu$...	Zn 67.34 Cu 32.66	64.80	8.015–8.075 8.012–8.090	8.043	7.796	7.679	Metal of the tint of antimony, pulverizable.	Do.
$Zn^3 Cu^2$..	Zn 60.73 Cu 39.27	60.35	8.048–7.969 8.378–8.288	8.171	8.039	7.783	Brilliant metal, resembling bismuth; less fragile than the preceding.	Do.
Zn Cu ...	Zn 50.76 Cu 49.23	50.30	8.352–8.261 8.301–8.374	8.304	8.263	7.947	Material with long fibers of a beautiful golden yellow.	1.40mm.
$Zn^2 Cu^3$..	Zn 40.74 Cu 59.26	40.10	8.389–8.268	8.329	8.412	8.119	Less yellow than the preceding.	2
$Zn Cu^2$....	Zn 34.02 Cu 65.98	34.50	8.351–8.430	8.390	8.410	8.345	Brass, ordinary yellow copper.	2.30
$Zn Cu^4$...	Zn 20.49 Cu 79.51	21.80	8.385–8.349	8.367	8.638	8.489	.....do.....	3.55
$Zn Cu^6$...	Zn 14.66 Cu 85.34	14.90	8.739–8.429	8.584	8.710	8.602	.....do.....	3.50
$Zn Cu^{10}$..	Zn 9.35 Cu 90.65	9.60	8.900–8.767	8.834	8.753	8.707	Substance resembling gold; similar.	2.50
Copper...	.....	.....	.....	.....	.....	.....	.....	5
Zinc.....	.....	.....	.....	.....	.....	.....	.....	3.25

We see by examining this table that the contraction of the two metals in these alloys is considerable from the second to the sixth; it seems to be at its maximum in the neighborhood of the alloy $Zn^3 Cu^2$, which is also remarkable like the preceding one in that it possesses none of the physical and mechanical properties which are utilized in the metals. They are eminently crystalline and fragile, and appear to be in the series of these alloys what the alloys $Sn Cu^3$ and $Sn Cu^4$ are in the alloys of copper and tin. The theoretical density has been calculated with the number 7.20 that I found to be the average of four concordant determinations on metallic zinc. Afterward the action that tempering, annealing, and rolling exert on the principal brasses utilized in manufacture

was determined; *a*, yellow brass containing 65 parts copper and 35 zinc; *b*, metal of 97 parts copper and 9 zinc.

1. *Alternate tempering and annealing.*

a. Brass.

TABLE 38.

	Density.	
	I. P = 77ᵛᵛ.071.	II. P = 83ᵛᵛ.571.
After rolling	8.407	8.406
After annealing	8.408	8.413
After tempering	8.412	8.415
After annealing	6.405	8.415
After tempering	8.417	8.418
After annealing	8.410	8.414

	Density.	
	III. P = 80ᵛᵛ.782.	IV. P = 80ᵛᵛ.076.
After rolling	8.409	8.417
After tempering	8.406	8.411
After annealing	8.401	8.400
After tempering	8.417	8.413
After annealing	8.407	8.411
After tempering	8.431	8.434

b. Similar.

TABLE 39.

	Density.	
	I. P = 92ᵛᵛ.588.	II. P = 94ᵛᵛ.688.
After rolling	8.812	8.817
After tempering	8.814	8.819
After annealing	8.813	8.814
After tempering	8.812	8.814
After annealing	8.813	8.815
After tempering	8.814	8.814

	Density.	
	III. P = 94ᵛᵛ.805.	IV. P = 92ᵛᵛ.202.
After rolling	8.818	8.818
After annealing	8.813	8.817
After tempering	8.812	8.816
After annealing	8.810	8.812
After tempering	8.814	8.813
After annealing	8.815	8.812

Thus tempering increases the density of annealed brass, *a*. These two operations do not cause any apparent modifications in the volume of *b*.

2. *Alternate annealing or tempering and rolling.*

a. Brass.

TABLE 40.

	Density.	
	I. P = 81ᵏᵍ.366.	II. P = 87ᵏᵍ.447.
After rolling	8.409	8.412
After tempering	8.410	8.411
After rolling	8.414	8.415
After tempering	8.431	8.427
After rolling	8.443	8.436
After tempering	8.433	8.436
After rolling	8.439	8.444
After tempering	8.437	8.437
After rolling	8.439	8.437
After tempering	8.445	8.443

	Density.	
	III. P = 76ᵏᵍ.412.	IV. P = 98ᵏᵍ.172.
After rolling	8.408	8.411
After annealing	8.411	8.415
After rolling	8.417	8.419
After annealing	8.409	8.417
After rolling	8.424	8.427
After annealing	8.398	8.402
After rolling	8.425	8.432
After annealing	8.414	8.424
After rolling	8.437	8.442
After annealing	8.421	8.430

TABLE 41.

	Density.	
	I. P = 92ᵏᵍ.848.	II. P = 94ᵏᵍ.365.
After rolling	8.819	8.820
After tempering	8.818	8.820
After rolling	8.813	8.814
After tempering	8.817	8.819
After rolling	8.819	8.818
After tempering	8.817	8.817
After rolling	8.818	8.816
After tempering	8.811	8.812
After rolling	8.822	8.811
After tempering	8.817	8.819

	Density.	
	III. P = 87ᵏᵍ.566.	IV. P = 93ᵏᵍ.566.
After rolling	8.819	8.819
After annealing	8.817	8.812
After rolling	8.816	8.817
After annealing	8.822	8.816
After rolling	8.818	8.818
After annealing	8.819	8.819
After rolling	8.815	8.818
After annealing	8.813	8.819
After rolling	8.819	8.820
After annealing	8.806	8.808

In these experiments the thickness was reduced from 20 millimeters to 2. It is shown by these numbers that the density of brass is diminished by annealing while it is increased by rolling, and that the density after a long series of operations varies but little. The density is increased still more by tempering. It is said by the experienced that annealing is preferable to tempering in working with brass.

Metal *b* (similar) shows no material variation in its volume after these prolonged operations, and after a considerable thinning. The same thing is true in regard to aluminium bronze, which, like the metal *b*, is capable of being worked to a remarkable degree.

§ VIII. BRONZES OF ALUMINIUM.

Alloy of copper and nickel.

The bronzes came from P. Mouri & Co's.

1*st. a. Bronze with* 10 *per cent. of aluminium.*

TABLE 42.

	Density.	
	I. P = 120gr.568.	II. P = 120gr.275.
After casting	7.705	7.704
After tempering	7.706	7.704
After annealing	7.706	7.705
After tempering	7.707	7.707
After annealing	7.703	7.704
After impact	7.703	7.703
After tempering	7.701	7.702
After impact	7.699	7.703

b. Bronze with 5 *per cent. of aluminium.*

TABLE 43.

	Density.	
	I. P = 120gr.575.	II. P = 139gr.161.
After casting	8.252	8.262
After tempering	8.259	8.259
After annealing	8.255	8.262
After tempering	8.257	8.262
After annealing	8.257	8.262
After impact	8.264	8.264
After tempering	8.263	8.264
After impact	8.263	8.265

Tempering, annealing, and mechanical action produce no noticeable variation in the volume of these alloys, of which the working is very regular.

2*d. Alloy of copper* 50, *zinc* 30, *nickel* 20, *used in the manufacture of coin for the Honduras.*

TABLE 44.

	Density.	
	I. P = 99kg.175.	II. P = 85kg.730.
After casting	8.539	8.539
After tempering	8.529	8.524
After annealing	8.524	8.520
After tempering	8.509	8.504
After annealing	8.510	8.504

	Density. III. P=110kg.004.
After casting	8.505
After striking	8.586
After annealing	8.556
After striking	8.589
After tempering	8.577
After striking	8.589

Density which is increased by mechanical action is diminished by the action of heat.

§ IX. SOFT IRON.—CAST IRON.—GLASS.

1st. *Soft iron.*—The metal was of good iron having the form of a parallelopiped. It was heated in a porcelain tube in the midst of a current of dry hydrogen. The annealing continued for two or three hours.

TABLE 45.

	Density.	
	I. P = 75kg.110.	II. P = 54kg.990.
After filing	7.852	7.849
After annealing	7.853	7.850
After tempering	7.852	7.845
After annealing	7.854	7.849
After impact	7.845	7.849
After annealing	7.845	7.845
After impact	7.842	7.841
After annealing	7.841	7.841
After impact	7.843	7.844
After repeated impact	7.844	7.847

	Density.	
	III. P = 75kg.110.	IV. P = 54kg.990.
After filing	7.853	7.852
After tempering	7.846	7.848
After annealing	7.853	7.853
After tempering	7.850	7.851
After impact	7.847	7.847
After annealing	7.846	7.846
After impact	7.845	7.844
After annealing	7.843	7.844
After impact	7.847	7.848
After repeated impact	7.846	7.850

2d. Gray cast iron—its permeability to liquids.—It was impossible to determine the variations in volume which gray cast iron undergoes when tempered or annealed, because it is permeable to liquids. This porosity is very great, whether the metal be heated in coal dust or exposed to the air during the operation.

a. Cast iron reheated in coal:

TABLE 46.

	Density.			
	I.	II.	III.	IV.
After annealing	7.069	7.098	7.114	7.069
After tempering	7.025	7.040	7.039	7.019
After annealing	6.844	6.914	6.933	6.914

My attention having been called to the great diminution in density, I weighed the samples, and ascertained that their weights increase considerably in water under the ordinary pressure. Thus they weighed—

	Gr.	Gr.	Gr.	Gr.
After the preceding annealing	75.512	75.668	70.191	73.134
And after 20 minutes in water	75.585	75.770	70.265	Not weighed.
Gain in weight	0.073	0.102	0.074	

The following table shows that this increase in weight takes place with non-oxygenized liquids like benzine, and that it is due simply to the absorption of the liquid, for by merely being exposed to the air cast-iron regains its original weight.

TABLE 47.

	Gr.	Gain in weight of the liquid.
Weight of a sample of fine gray steel annealed in coal	64.937	
Weight of this sample after 20 hours' immersion in benzine	65.018	0.081
Weight of this sample after 24 hours in the air	64.940	
Weight of this sample after a second annealing of 3 hours	64.996	
Weight of this sample after 3 hours' immersion in benzine	65.110	0.114
Weight of this sample after 24 hours in the air	65.001	
Weight of this sample after a third annealing of 3 hours	65.100	
Weight of this sample after 20 hours' immersion in benzine	65.275	0.175
Weight of this sample after 24 hours in the air	65.103	

Cast iron, known to be porous, was filed to a thickness of 1 millimeter over the whole surface, then immersed in benzine. The permeability was restored in the inner layers.

A third series of experiments was made in order to determine the effect of annealing and tempering on this porosity, and the results are here given:

TABLE 48.

	Gr.	Gain in weight.
Weight of a sample of tempered cast iron	70.215	
Weight of a sample after a half hour in benzine	70.270	0.055
Weight of a sample after 48 hours in the air	70.214	
Weight of a sample after 24 hours in benzine	70.311	0.095

	Gr.	Gain in weight.
Weight of a sample after 48 hours in the air	70.216	
It was thoroughly annealed.		
Weight in the air	70.304	
Weight after 18 hours in benzine	70.395	
		0.091
Weight after 48 hours in the air	70.306	
Weight of a sample of annealed cast iron	75.733	
Weight of same after half an hour in benzine	75.820	
		0.087
Weight of same after 48 hours in air	75.735	
Weight of same after 24 hours in benzine	75.875	
		0.140
Weight of same after 48 hours in air	75.735	
It was tempered hard.		
Weight in the air	75.761	
Weight after 18 hours in benzine	75.893	
		0.132
Weight after 48 hours in air	75.758	

b. Cast iron reheated in a crucible placed in the muffle.

TABLE 49.

Weight of a sample of fine gray cast iron annealed in the open air	63.652	
Weight of this sample after an immersion of 20 hours in benzine	63.830	
		0.078
Weight of this sample after being exposed to the air for 24 hours	63.755	
Weight of this sample after a second annealing of 3 hours in the muffle	60.362	
Weight of this sample after 20 hours' immersion in benzine	60.493	
		0.131
Weight of this sample after 24 hours' exposure to the air	60.362	
Weight of this sample after a third annealing in the muffle	55.523	
Weight of this sample after 20 hours' immersion in benzine	55.700	
		0.177
Weight of this sample after 24 hours' exposure to the air	55.525	

Steel, soft iron, brass, and bronze under the same conditions do not vary in weight.

3d. *Glass and crystal.*—MM. Chevandrier and Wertheim have shown* that annealing increases the density of glass and crystal. I made some experiments on these materials as limits of compression in order to determine whether the alternate action of tempering and annealing affects this density. I found that tempering materially diminishes this density, while annealing tempered glass increases it, and reciprocally.

TABLE 50.

Crystal of M. Maës.

Samples weighing from 11 to 186 grammes.

	Density.				
After annealing	3.110	3.111	3.110	3.110	3.110
The same not annealed	3.104	3.103	3.104	.....	.....
The same tempered	3.102	3.103	3.101	3.099	.....
These last annealed	3.103	3.109	3.107	3.106	.....

* MM. Chevandrier and Wertheim, *Ann. de Chim. et de Phys.*, 3 série, t. xix, p. 137.

Flint of M. Feil.

Samples weighed 60 to 70 grammes.

	Density.	
After annealing	3.610	3.610
After tempering	3.598	3.598
After tempering	3.602	.....
After annealing	3.605	.....

Crown of M. Feil.

	Density.		
After annealing	2.551	2.551	.....
After tempering	2.544	2.543	.....
After tempering	2.544	2.544	2.543
After annealing	2.551	Broke.	Broke.

RÉSUMÉ.

1st. The alloys of copper and tin prepared in atomic proportions exhibit a sensible liquation with the exception of those which correspond to the formulæ $Sn\ Cu^3$ and $Sn\ Cu^4$. This liquation, slight from the alloy $Sn\ Cu^3$, increases in the alloys which differ from it in their composition, but it is especially great in the alloys containing a large proportion of tin. By reason of this fact it has been impossible to determine the fusibility of any except the two alloys given above (§ I).

2d. The alloy $Sn\ Cu^3$ is characterized by special properties. It has a different color from the others; it is pulverizable; it exhibits no sensible liquation, and it is of all the various alloys of copper and tin, the one in which the contraction is at its maximum. It is, then, the homogeneous alloy of copper and tin, as the alloy $Ag^3\ Cu^4$ is the homogeneous alloy of copper and silver. In paragraph II is given the density of the principal alloys of copper and tin prepared in atomic proportions. An idea of their hardness is given in the following paragraph.

3d. The bronzes rich in tin (18 to 22 per cent.) increase in density with tempering; and annealing lessens the density of tempered bronze, but in a less proportion. The density is considerably increased by the alternate action of tempering and annealing, and of the press. These effects, the reverse of those in steel, coincide with the fact that tempering softens bronze while it hardens steel (§ IV).

4th. This softening, discovered by D'Arcet, is not sufficient to allow of this bronze being worked cold for industrial purposes. It was shown n paragraph IV that this metal—extremely hard when cold and pulverizable at red heat—is forged and rolled at dark red heat with remarkable facility. This fact enabled me, in common with M. Champion, to succeed in the manufacture of tamtams, and other sonorous instruments, by the method followed in the East.

5th. Tempering produced no apparent softening in the bronzes less rich in tin (12 to 6 per cent.); and if they are tempered for industrial uses it is more especially in order to detach the oxide produced during the reheating of the matter in the course of the operations (§ VI).

6th. It was found that in the axis of a cannon, and especially toward the muzzle, there are some parts very rich in tin and in zinc. Yet the

axis is less rich in tin than the periphery. The density does not increase from the muzzle to the breech.

7th. Bronzes of 3 and 4 per cent. of tin possess some great advantages and no important disadvantages, when used in the manufacture of medals.

8th. The density of copper (§ VI), subjected alternately to mechanical action, then to tempering or annealing, displays inverse variations according as it is exposed to the air or sheltered from it during the reheating; while in the first case the mechanical action increases the density, in the second mechanical action diminishes the density.

9th. Some copper, non-porous, becomes sufficiently so by being reheated in coal dust to acquire permeability to liquids (§ VI).

10th. Intense heat, prolonged rolling, and the oxide which forms when the metal is exposed to the air during reheating, render small quantities of iron permeable to liquids.

11th. The introduction of small quantities of iron into the copper gives to it considerable tenacity without destroying its ductility; while rolled copper offers a resistance of 28 kilograms per square millimeter, that of ferrous copper rolled in the same conditions attains to 40 kilograms. The hardness increases equally (§ VI).

12th. The alloys of copper and zinc $Zn^2\ Cu^3$, $Zn^2\ Cu$, are brittle, like the bronzes $Sn\ Cu^3$, $Sn\ Cu^4$; they have none of the physical properties utilized in the metals, and the maximum of contraction takes place near them (§ VII).

13th. Mechanical action increases the density of yellow brass, and this effect is counteracted in part by tempering, and especially by annealing. It is thought that annealing is preferable to tempering in working with brass.

14th. Mechanical action, tempering, and annealing, do not sensibly change the volume of similor and of the bronzes of aluminium, alloys remarkable for the facility with which they can be worked (§ VIII).

15th. Gray cast iron heated in coal dust or even in an empty box surrounded with coal, acquires such a porosity that it becomes very permeable to liquids (§ IX).

16th. It becomes equally porous when heated in an empty crucible placed in a muffle, and when the sample is filed in order to remove the oxide which is formed. Copper is not porous in this last condition.

17th. I attempted to determine minutely the modifications which the density undergoes through tempering, annealing, and mechanical action, repeated alternately a certain number of times, and the effects observed were different. While mechanical action increases the density of the bronzes rich in tin, especially (Table 8) of porous copper (Table 28), of copper alloyed with iron (Table 35), of brass, it evidently diminishes the density of copper exposed to the air during reheating (Table 23), and it produces no noticeable alteration in the volume of similor or of aluminium bronze. Tempering produces on brass, and especially on the bronzes rich in tin previously annealed, an increase in density (Tables 5, 6, and 7) contrary to what takes place in steel (Table 11), copper (Tables 27 and 28), and glass (Table 50).

It will be perceived that tempering diminishes the density of a body, because the surface cooled before the center, cannot contract freely by reason of the resistance that the interior parts dilated at this moment offer to contraction.

Copper and tin and copper and zinc contract when they unite, and for the rest, the alloys formed experience large liquation. May it not be possible that by slow cooling a part of the copper and of the tin, or of

the zinc separates, a phenomenon which should cause a diminution in density, and which cannot take place when the cooling is sudden. I am endeavoring to clear up this point by the study of various slight chemical actions on these alloys, and by examining the modifications which take place in the density of the alloys formed with dilatation of the metals which constitute them.

I may be allowed, in closing, to thank M. Dumas and M. Poussierre, for the facilities for working which they procured for me at the mint where these researches were carried on.

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